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Automobile Emission Control The Current Status and Development Trends as of March 1976

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The Current Status and Development Trends
As of March 1976

A Report to the Administrator,
U.S. Environmental Protection Agency

Prepared by

Technology Assessment and Evaluation Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control

April 1976

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Table of Contents

1. Introduction 1-1

2. Conclusions and Summary 2-1

2.1 Conclusions 2-1
2.2 Discussion of Conclusions 2-3
2.3 Significant Development and Trends 2-8

3. Allocation of the Benefits of Improved Technology Among Different Objectives. 3-1

3.1 Why All Vehicles are not the same 3-1
3.2 How Emphasis on Selected Parameters Can Influence the Final Product 3-2
3.3 Some Examples of Differences in Emphasis 3-3
3.4 Summary 3-13

4. Fuel Economy and Cost 4-1

4.1 Introduction 4-1
4.2 Fuel Economy Potential of the 1977 Models. 4-1
4.3 Update of the 75/76 Fuel Economy Performance 4-5
4.4 Fuel Economy Projections for the Stringent Emission Standards. 4-7
4.5 Cost Ranges. 4-17

5. The Impacts of Permitting or Not Permitting Service of Catalytic Converters Once During 50,000 Durability Mileage Accumulation Schedule 5-1

5.1 Background 5-1
5.2 Catalyst Service Without a Catalyst Change 5-2
5.3 Catalyst Service via Catalyst Replacement. 5-4
5.4 Fuel Economy and Cost Impacts of a Catalyst Change . . 5-9
5.5 Summary. 5-14

6. Industry Status 6-1

6.1 Industry Status - 1977 Model Year 6-1
6.2 Industry Status - Post-1977 Model Year 6-2

7. Individual Manufacturers Reviews. 7-1

7.1.1 American Motors (AMC). 7-1
7.1.2 Chrysler 7-13
7.1.3 Ford 7-31
7.1.4 General Motors (GM). 7-44

Table of Contents (con't)

7.2 Independent Developers 7-67

7.2.1 Dresser 7-67
7.2.2 Ethyl 7-73
7.2.3 Gould 7-82
7.2.4 Yamaha. 7-88
7.2.5 Questor 7-91

7.3 Foreign Manufacturers. 7-96

7.3.1 BMW 7-96
7.3.2 British Leyland 7-98
7.3.3 Citroen 7-102
7.3.4 Daimler-Benz. 7-104
7.3.5 Fiat. 7-112
7.3.6 Fuji Heavy Industries (Subaru). 7-116
7.3.7 Honda 7-119
7.3.8 Mitsubishi. 7-123
7.3.9 Nissan (Datsun) 7-135
7.3.10 Peugeot 7-139
7.3.11 Porsche 7-142
7.3.12 Renault 7-148
7.3.13 Rolls-Royce 7-150
7.3.14 Saab. 7-153
7.3.15 Toyo Kogyo (Mazda). 7-157
7.3.16 Toyota. 7-162
7.3.17 Volkswagen (VW) 7-167
7.3.18 Volvo 7-173

Appendixes . . . .

Appendix 1. . . . . A1-1
Appendix 2. . . . . A2-1

SECTION 1

INTRODUCTION

This report is a summary of the current technical status and development trends in the automobile emission control field. This report has been prepared for the Administrator of the U.S. Environmental Protection Agency (EPA) to inform the Administrator and other interested parties of the current status in the emission control technology area. The

This report contains a summary and evaluation of the development programs of automobile manufacturers and other organizations involved in the development of automobile emission control technology.

The period of time of interest for this report is the 1977 model year and post-1977 (1978-1980) time period. The post-1977 time period is considered as a range related to the current deliberations by Congress on the Clean Air Act.

Most of the information in this report came from manufacturers' responses to a request from EPA. Most of the responses from the manufacturers were received during December 1975 to February 1976, so the information pertains to the period of time around the end of calendar year 1975. The specification of the time to which the data relate is important in an area like emission control technology, in which progress is continually being made.

Copies of the responses submitted by the manufacturers are available for public inspection at the EPA Freedom of Information Center at the EPA Headquarters Building, 401 M. Street, S.W., Washington, D.C. A copy of the letter request from EPA and the date of the responses are included in Appendix 1.

Other data used in the preparation of this report were: a) 1975 and 1976 certification results, b) 1977 Part I applications for certification, and c) the technical literature.

This report is the fifth in a series of reports on the same subject. The earlier reports were:

Automobile Emission Control - A Technology Assessment as of December 1971.
Automobile Emission Control - The State of the Art as of December 1972.
Automobile Emission Control - The Development Status as of April 1974.
Automobile Emission Control - The Technical Status and Outlook as of December 1974.

The nomenclature used in this report for emission test results and standards is a triplet abbreviation. In this shorthand notation for example, the 1975 Federal standards of 1.5 grams per mile hydrocarbons, 15.0 grams per mile carbon monoxide and 3.1 grams per mile oxides of nitrogen are abbreviated 1.5 HC, 15.0 CO, 3.1 NOx with the understanding that the dimensions are grams per mile. Similarly, a vehicle that achieved 0.2 grams per mile hydrocarbons, 2.2 grams per mile carbon monoxide and 0.22 grams per mile oxides of nitrogen on a given test would be said to achieve the levels of 0.2 HC, 2.2 CO, 0.22 NOx.

The current emissions standards are thus:

1975/76	Federal; 1.5 HC, 15.0 CO, 3.1 NOx
1975/76	California; 0.9 HC, 9.0 CO, 2.0 NOx
1977	California; 0.41 HC, 9.0 CO, 1.5 NOx
1977	Federal; 1.5 HC, 15.0 CO, 2.0 NOx
1978	50-State; 0.41 HC, 3.4 CO, 0.4 NOx

SECTION 2

CONCLUSIONS AND SUMMARY

2.1 Conclusions

The conclusions listed below apply to the time this report was being prepared, March 1976. In a technical area like emission control technology, in which the rate of change can potentially be rapid, new developments may require modifications of conclusions that were made previously.

The major conclusions of the report are:

1. The passage of the Energy Policy and Conservation Act, PL 94-163, has created a new set of requirements for the industry that have impacted and will continue to impact on the development of future emission control systems. Mandated fuel economy goals will require that fuel economy become a high priority design constraint. Because of time, budget and manpower limitations, this may stretch out the development period for advanced emission control systems.

2. Development of Emission Control Technology has slowed down during the past year compared to the rate of technological progress reported in the status reports of the previous years.

3. The earliest that the statutory standards, 0.41 HC, 3.4 CO, 0.4 NOx could be met is model year 1980. It just might be possible to meet 0.41 HC, 3.4 CO, 1.0 NOx in 1979 on a limited number of vehicles if the industry started now an expanded effort with high emphasis on emission control technology development. Given the current slow pace of development, it will probably take the industry longer.

4. The technical feasibility of meeting emission standards for model year 1977 down to 0.9 HC, 9.0 CO, 2.0 NOx is unquestioned. The standards of 0.41 HC, 9.0 CO, 1.5 NOx are also feasible, at least in California where recent differences between Federal and California protocols for determining the compliance of 50,000 mile durability vehicles may make the California requirements less stringent than a numerically equivalent Federal standard. The differences between the California and Federal protocols means that a given standard which is met in California, for California, may not be able to be met nationwide with the same technology in the same year or even one year later.

5. In the 1978-79 timeframe meeting standards of 0.41 HC, 3.4 CO, 2.0 NOx nationwide can be projected for about 47-80% of the population without a catalyst change and 64-100% with a catalyst change. At standards as low as 0.41 HC, 3.4 CO, 1.0 NOx and 0.41 HC, 3.4 CO, 0.4 NOx a catalyst change is much more likely since the catalyst change approach may be more attractive from the standpoint of fuel economy or may be the only viable technology available for some manufacturers.

However, from the standpoint of emission performance in the field, the question of whether or not catalysts will actually be changed for in-use vehicles overshadows the technically related design and certification issues. Not permitting catalyst replacement or service during the 50,000 mile useful life will generally delay the time at which most manufacturers will be able to meet future stringent standards.

6. Hydrocarbon (HC) control continues to be the most common emission control problem for most manufacturers at any future emission level. This is considered to be a serious problem in terms of meeting future HC standards, especially 0.41 HC because unless manufacturers improve or modify the emission control systems in use today spark timing recalibrations to control HC levels may degrade fuel economy.

2.2 Discussion of Conclusions

1. Impact of PL 94-163

The passage of the Energy Policy and Conservation Act set sales-weighted fuel economy standards of 18 miles per gallon (mpg) for 1978, 19 mpg for 1979 and 20 mpg for 1980. The standard for 1985 is 27.5 mpg, the standards for the years 1981-1984 are to be set by the Secretary of the Department of Transportation, DOT. This new legislative requirement has several impacts:

a. Up until the legislation was passed, the manufacturers were working toward a voluntary 40% improvement in fuel economy by 1980 with the assumption that a 5-year freeze in the emission standards would be granted. As of the writing of this report Congress is still considering changes to the Clean Air Act that may influence the 5-year freeze assumption, but the concrete fact that the manufacturers now know is that instead of a voluntary program their fuel economy is now subject to mandatory controls.

b. The requirement to meet fuel economy standards has dramatically increased the desirability for the manufacturer of selecting emission control systems with emission control potential that is better than just needed to meet a given set of emission standards. The oxidation catalyst system is an example of a system that was more technology than was just barely needed to meet the 1975/76 standards of 1.5 HC, 15.0 CO, 3.1 NOx, but that had potential to be calibrated at that standard for improved fuel economy. Oxidation catalyst systems were originally developed to meet much lower HC and CO standards and thus had the "cushion" to be recalibrated for optimum fuel economy. Systems that have a similar emission control cushion at even lower emission standards are very attractive if they can be calibrated for improved fuel economy as were the 1975 oxidation catalyst systems. Work is just beginning on such advanced systems. Systems that employ a combination of thermal and catalytic emission control along with improved engine modifications, currently look promising for both good fuel economy and emissions control.

2. Slowdown in Development of Technology

Development of emission control technology has slowed down from last year's pace for several reasons. Passage of the Energy Policy and Conservation Act and uncertainty in the future emission standards are the most important ones. The effects of the fuel economy legislation are threefold. First, meeting any standard (for anything) may require a stretch out in the research, development, design and production requirement so that the new standard can be designed to be met. Secondly, even if the standard requires no development at all in order to meet it, time, effort and expense are required to demonstrate that it is met. For example, consider an automobile performance standard of a zero to 30 miles per hour acceleration time of 40 seconds. Everybody in the technical community will agree that such a standard could be met by all cars right now. However, proving that every car meets it would take time, manpower and dollars that could otherwise be devoted to development. Third, and perhaps most important, the manufacturer's primary emphasis now is on fuel economy, not solely on emissions. The manufacturers have to apportion their technical effort where they feel that it will do them the most good. With fixed total resources, effort that was directed toward achieving more stringent emission control is bound to lose out to work toward improving fuel economy, especially since the same engineering staffs are generally involved.

The uncertainty as to what the emission standards will ultimately be has been stated by the manufacturers to be a problem for a long time, and was stated in last year's EPA report on this subject as a reason why the development progress was not as rapid as desirable. With the Congress still deliberating changes to the Clean Air Act as this report is being written, it is clear that the manufacturers are delaying decisions to see what happens. Because of the demand on their manpower caused by the fuel economy legislation, and the fact that they cannot commit the resources to fully develop emission control systems for all of their models for every possible future standard, manufacturers have not been able to put concentrated effort into designing and developing the fleets of vehicles needed to determine how to meet any given future standard.

Additional reasons that development progress has slowed down could involve new regulatory requirements. The possibility of an as yet undetermined sulfuric acid emission standard has impacted on the rate of development progress. Also, EPA has proposed that the manufacturers meet new SHED evaporative emission standards, and assembly line test requirements. Further, EPA has proposed that those manufacturers that produce Light Duty Trucks (LDT), meet more stringent LDT standards for an expanded vehicle class that includes for the first time trucks with gross vehicle weights in the 6000-8500 pound GVW range. All of these new regulations will require expanded development and testing to insure compliance. The same engineering staffs are generally involved in all of these activities.

3. Feasibility of Meeting Statutory Standards by Some Date

1980 is the earliest that 0.41 HC, 3.4 CO, 0.4 NOx could be met because the required development efforts have not been done. Most manufacturers have just a few cars on test when they really need fleets of vehicles to investigate the systems. This estimate of 1980 is based on the running of two vehicle fleets in series, both fleets somewhat larger than the usual pre-certification fleets. These fleets would include a representative model or models of each type, since different catalysts and control approaches have to be screened. Time required for running these fleets, analyzing the results and getting certified indicate that model year 1980 is the earliest date. Meeting these standards in 1980 would require that the development be expanded greatly starting now. If the effort is not expanded until later, it will of course, take longer. If the current low level of effort continues, it will be later than 1980.

Standards of .41 HC, 3.4 CO, 1.0 NOx could only be met in model year 1979 on a limited number of vehicles. But even this would entail a high risk effort for the manufacturers, since there is now only enough time to run one development fleet. It is estimated that the manufacturer would pick a prime system using a 3-way catalyst plus a carbureted feedback control, and possibly an oxidation catalyst back-up system and go with those, because the time is too short to do much more development before commencing durability testing. If a manufacturer were required to meet 0.41 HC, 3.4 CO, 1.0 NOx on less than 100 percent of his production he could do it two ways: 1) he could concentrate on a given model or models or 2) he could try to get a fraction of all his models equipped with the system needed, as is done currently for California.

The above estimates of feasible timing for meeting emission standards are based on the assumption that the manufacturers' development efforts are increased over what is being done now, and that the increased effort is directed primarily toward emission control technology. If a manufacturer places greater emphasis in his development effort on fuel economy than emissions, the lead time for meeting the statutory standards will be stretched out, possibly by one to three years with the best estimate being two years for nationwide introduction. This suggests that 1981 and 1982 are considered to be a reasonable earliest estimate of when 1.0 and 0.4 NOx respectively could be met.

4. Direct Comparison of Federal to California Standards is no Longer Feasible

Because of evolving differences between California and Federal certification protocols, a Federal standard of 0.41 HC may be more stringent than a California standard of 0.41 HC. In accordance with currently allowable California protocol, a durability car may be allowed to exceed the standards during the mileage accumulation. This is not permitted by Federal certification protocol. What this means is that the vehicles that meet given standards for California may not be able to meet the same standards on a nationwide basis. Therefore, caution should be exercised in extrapolating California certification experience to nationwide application.

Another aspect of certification protocol involves the issue of methane versus non-methane HC emission standards. Both California and EPA are currently evaluating this issue and may reach different conclusions. This can impact on the relative stringency of nominally identical numerical values.

5. The catalyst change issue is discussed in Section 5.

6. HC Control Problem

HC control is a problem common at all potential emission standard levels. Down to control levels of 0.41 HC, 3.4 CO, 2.0 NOx or 0.41 HC, 9.0 CO, 1.5 NOx, control of HC is the biggest problem. This is due to the technology projected for use down to these levels, the oxidation catalyst plus EGR system.

Because HC is so significant an emission control problem the proportionally large reduction from the current Federal standards of 1.5 HC to the 0.41 HC levels may be too great to be accomplished in one step. Solely from a technical standpoint a potentially more attractive schedule might be to have Federal standards of about 0.90 to 0.60 HC (and CO from about 9.0 to 6.0) as an intermediate step before 0.41 HC was required. This approach may be desirable from a technical standpoint, because implementation of emission controls in production vehicles is better achieved on an incremental basis than in major steps.

At emission levels of 0.41 HC, 3.4 CO, 1.0 NOx or 0.41 HC, 9.0 CO, 1.0 NOx, control of all three pollutants presents major problems. This again is due to the technology projected as likely to be used at these levels, i.e. systems employing a 3-way catalyst. For oxidation catalyst systems it can roughly be said that if one can achieve the HC control needed, the CO control is almost assured. With the 3-way catalyst approach, however, the lack of excess air makes CO control as much of a problem as HC control. NOx control is also a problem of equal magnitude at these levels.

At levels below 1.0 NOx, like 0.41 HC, 3.4 CO, 0.4 NOx, control of all three pollutants remains a major problem. The dual catalyst system considered most likely to be used at this level has always had NOx control problems, and since oxidation catalysts are part of the system, HC problem remains the same as at other levels. The engine calibrations required for this system may cause the engine-out emissions for HC and CO to be somewhat higher than for other systems, thus further increasing the difficulty of controlling HC and CO with this system.

2.3 Significant Developments and Trends

The 3-Way Catalyst - New Emphasis

Systems using a 3-way catalyst now appear to be in the forefront of emission control technology development to meet NOx levels of 1.5 and below. There are several reasons for this:

a. Most manufacturers may be assuming that the long-range NOx standard will be about 1.0 NOx. At 1.0 NOx the 3-way catalyst system looks somewhat more attractive than the dual catalyst system, while at 0.4 NOx the roles are reversed.

b. Concern over a possible sulfuric acid emission standard has led to higher priority being given to systems like the 3-way catalyst which use little or no excess air. Indications are that both catalyst formulation and the low O_2 levels are responsible for the low sulfuric acid emissions from systems using a 3-way catalyst.

c. The recent changes* in the lead and phosphorus specifications for certification fuel may greatly enhance the conversion efficiency of 3-way catalysts at high mileage. How much the NOx efficiency will be improved has not yet been determined. The HC and CO effect should be similar to the beneficial effect seen for oxidation catalysts.

d. Packaging may be easier for the 3-way catalyst than for the dual catalyst system since only one catalytic unit is generally needed.

e. In general, progress has been more rapid in the last year or so in the 3-way catalyst area, compared to the separate NOx reducing catalyst used in the dual catalyst system.

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* For model year 1977 certification, EPA revised the minimum requirements for lead and phosphorus content in the unleaded durability fuel because extensive field surveys of nationwide commercial fuel showed that actual lead and phosphorus content in commercial fuels was below the levels previously specified for durability test fuel. Thus the current specification more correctly reflects the characteristics of commercially available fuel.

f. Recent work, reported primarily by Ford, on the oxygen storage and release on 3-way catalysts may have significant ramifications. The rate of oxygen storage and release on 3-way catalysts apparently can influence the width of the window where high HC, CO, and NOx conversion is obtained, if the air fuel ratio fluctuates. The results may be interpreted in the following way: If air/fuel ratio transients of a given type are not detrimental to the operation of a 3-way catalyst (they appear to help), then the very precise control of input air/fuel ratio thought necessary for successful 3-way catalyst operation may not be required. This means that carbureted systems may be adequate. This has important control technology, cost, and leadtime implications. Expensive fuel injection systems which would take a long lead time to introduce may not be needed to make the 3-way approach work. This subject, however, is somewhat speculative, since the work reported to date has concentrated on air/fuel variations that are controlled in both frequency and amplitude. It is not known now if the presumably more random air/fuel fluctuations (in both frequency and amplitude) of a carburetor approach will be good enough to provide the desired high conversion efficiency for all three pollutants. It is, however, a promising area.

NOx Catalysts - Some Progress, Some Problems

Despite the limited amount of vehicle testing, some progress has been made in the development of some NOx catalysts. Other NOx catalysts that appeared to be attractive last year look less attractive now.

Chrysler may now have one of the most attractive metallic NOx catalysts. Their comprehensive in-house development program for this type catalyst appears to be bearing fruit. A vehicle test showed NOx levels as low as

0.20 NOx at approximately 20,000 miles, the most impressive combination of low NOx and high mileage reported to date. However, the catalyst failed shortly thereafter. The reasons for the catalyst failure are not known at this time, although it is generally conceded that metallic NOx catalysts are more prone to being harmed by engine malfunctions. Analyzing failed metallic NOx catalysts to determine the cause of failure is also much more difficult than for ceramic/noble metal catalysts, so this is another problem in discovering the reason or reasons for the failure. However, the Chrysler results are sufficiently positive, on balance, to rate Chrysler as one of, if not the, current leader in NOx catalyst development and demonstration.

Gulf may have also developed a promising NOx catalyst. Engine dynamometer tests at GM indicated a 92% NOx conversion efficiency at the end of the simulated 50,000 mile durability test. Although vehicle tests to substantiate these results have still not yet been reported, this appears to be an attractive candidate. There may be a drawback to this catalyst, as there was with the attractive Nippon Denso catalyst (also tested by GM) in that the level of active material may be too high to be deemed commercially feasible.

The perovskite catalyst, developed by DuPont may also be an attractive NOx catalyst, especially if the lattice structure can be used to stabilize ruthenium. Testing of perovskite NOx catalysts has just started, however.

International Nickel has also reported the development of promising NOx catalysts, based on Copper, Chromium, and Nickel.* Alloys labeled IN-1013 and IN-1050 are the most recent versions. Net NOx conversion efficiencies in the 70 to 80 percent range were measured after dynamometer testing which simulated 25,000 miles. The catalyst IN-1013 is also said to be sulfur tolerant, but more detailed characterization of the emissions is required to more properly assess the particulate emissions. The same phenomenon noted in the above discussion of the 3-way catalyst, the potential benefits of air/fuel ratio cycling, was also noted in this work.

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* Copper-Chromium-Nickel Alloys for NOx Reduction Automotive Emission Control Catalysts, by P. D. Goodell, et. al., SAE Paper 760318, presented at the Automotive Engineering Congress and Exposition, Detroit, MI February, 1976.

As long as fuel sulfur levels remain at the level of 0.03 percent by weight (typical of today's fuels) the attractiveness of the catalyst GEM-68 developed by Gould, Inc. is less than it was one year ago. The catalyst GEM 68 is physically attacked by sulfur and cannot be used with 0.03 percent by weight sulfur fuel. Because of this setback, and because other systems have advanced, the Gould system can no longer be considered as the leading system in NOx catalyst development. Gould is working on a sulfur tolerant catalyst, GEM 69, which may re-establish the viability of their system, but it is too early to make definite conclusions.

Revised Certification Fuel Specifications

For model year 1977 EPA has adjusted its lead and phosphorus fuel contaminant specifications for durability fuels to reflect the contaminant composition of fuels commercially available.* This has resulted in significantly reduced lead and phosphorus concentration in the current certification fuel. This has a significant, beneficial, effect on the performance of vehicles equipped with catalysts.

Based on preliminary results with oxidation catalyst systems, the effect on deterioriation factor, DF, is shown below in Table 2-1.

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* For model year 1977 certification, EPA revised the minimum requirements for lead and phosphorus content in the unleaded durability fuel because extensive field surveys of nationwide commercial fuel showed that actual lead and phosphorus content in commercial fuels was below the levels previously specified for durability test fuel. Thus the current specification more correctly reflects the characteristics of commercially available fuels.

Table 2-1

Effect of Revised Certification Fuel Specifications on Deterioration Factor

	Difference (DF old-DF new)		Ratio (DF new/DF old)	
Pollutant	Average	S.D.*	Average	S.D.*
HC	0.468	0.466	0.742	0.255
CO	0.441	0.561	0.767	0.385
NOx	-0.011	0.191	1.027	0.166

* S.D. - Standard deviation

The DF's are reduced by about 25 percent for HC and CO, while the NOx is up about 3 percent. Since the average NOx DF for oxidation in catalyst systems is less than 1.0 usually, the slight increase is not considered a major problem.

Since the fuel contaminants primarily affect the high mileage emission values it is probably reasonable to assume that the 50,000 mile values for HC and CO would also be reduced by about 25 percent since the 4,000 mile values would be little affected by the reduced fuel contaminant levels. This significantly increases the chances of successfully certifying at low HC and CO levels.

The DF effect alone, if translated into a fuel economy improvement, would be about 5 to 9 percent.

The effect of the change in certification fuel on other catalyst types has yet to be quantified, but it is believed that the 3-way catalyst will also benefit substantially.

Electronic Controls

The vehicles of the future may feature all-electronic control systems. The trend is in that direction, and acceleration is predicted.

Components that can be classified as electronic are used on some vehicles today. Primarily used in the ignition systems, today, this type of component was first given wide use by Chrysler. Another current use of electronic components today is in the Electronic Fuel Injection (EFI) systems found on some foreign and a few domestic automobiles.

This current use of electronics in automobiles is only the start of a trend that is likely to lead to all-electronic control of engine parameters. Some vehicles have electronic spark timing control for model year 1976, the Chrysler "ESA Lean Burn" vehicles. These vehicles are more important for their electronic spark timing than for their lean calibrations, since other vehicles have operated as lean in the past. The trend to electronic spark timing will accelerate in 1977 as other manufacturers, GM among them, introduce their versions of electronic spark timing.

Control of the spark timing electronically is only one type of electronic control. Systems are now under development that will control spark timing, spark duration, (possibly even spark energy and the number of spark plug firings), EGR rate, air/fuel ratio, etc.

These systems may use sensors and feedback loops to adjust the parameters to the desired values. Systems to control air/fuel ratio, for example, are under development for use with 3-way catalysts.

Future systems will involve three basic parts; sensors, an electronic control unit (ECU), and servos or actuators.

The devices that act as sensors could sense a multitude of parameters. Among these parameters are ambient temperature, coolant temperature, oil temperature, engine speed, throttle position, intake manifold pressure, driveshaft torque, ambient humidity, ambient pressure, engine air/fuel ratio, spark knock intensity, vehicle speed, vehicle acceleration, time since "key-on", EGR rate, engine air flow, engine fuel flow, catalyst temperature, road grade etc., etc., etc. The rates of change of these parameters with time could also be sensed.

The ECU will probably take the form of a small specialized computer, which will take the information from the sensors, process it, and provide the signals to the servos. The ECU could also act as a diagnostic tool, via plug into a computer programmed to detect malfunctions. Maintenance could be improved.

The servos or actuators will control one or more of several parameters. Some of the parameters could be: transmission gear ratio, torque converter lock-up clutches, engine fuel flow, engine air/fuel ratio, EGR rate, cold enrichment, acceleration enrichment, spark timing, spark duration, other ignition system parameters, valve timing, exhaust system valves (EFE and/or start catalyst valves), etc. All of the control could be done dynamically, with the controlled parameters varying continually as the vehicle is in operation.

Each of the three parts of the system, sensors, ECU, and servos is currently under development. The problems with the sensors and servos are to find inexpensive, precise units that will withstand the automobile environment. The major problem with the ECU is not the device itself, but "telling it what to do",i.e. programming it. Since the electronic control parameters offer more flexibility than has been heretofore available, (spark timing computed from many input signals instead of just spark timing dictated by engine speed and manifold vacuum, for example) developers are rethinking the problem of "optimum"* calibrations and controls all over again, in light of this new control flexibility. Much work remains ahead to determine what the desired control functions should be.

Improved Warm-Up Control and Heat Conservation

Improved warm-up emission control devices are being explored more now. The improvements are being made both in terms of start-up fuel metering (vaporizing chokes, EFE, etc.) and in catalytic systems, start catalysts for example. Significant benefits are possible, since for catalyst systems, about 45% to 50% of the HC, and about 65% of the CO are emitted during the cold transient (Bag 1) phase of the test. Technology used to reduce cold-start HC emissions may have beneficial fuel economy impacts, since compared to the case of using spark retard all of the time, more control of the cold-start emissions may permit more nearly optimum calibrations.

In addition to improved warm-up work, more emphasis is being placed now on heat conservation techniques. The primary benefits of heat conservation techniques, such as port liners, low conductivity coatings, and/or thermal reactors, is that they help maintain higher exhaust gas temperatures in the exhaust systems and promote additional oxidation in the exhaust system. The effects in reducing HC by this method could yield fuel economy benefits. Side benefits in reduced heat rejection to the coolant also are possible.

The effects of systems that incorporate both heat conservation techniques and improved warm-up control remain to be quantified, although the benefits are considered to be substantial.

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* What the "optimum" is, that is, which of the several desirable attributes of a vehicle are to be enhanced can mean different things to different people. This report considers that emissions should be optimized. This subject is discussed further in Section 3.

Advanced Fuel Metering - High Emphasis

More precise and controllable fuel metering systems are a key element of almost every future emission control system. Activity is underway to develop and test a multitude of approaches.

Advanced fuel metering includes systems other than fuel injection. Electronic fuel injection systems and mechanical fuel injection systems like Bosch's L-Jetronic and K-Jetronic systems, respectively, have received a great deal of attention from foreign manufacturers, and some interest from the domestic manufacturers. Carbureted systems now under development may prove to be as good or better than today's multiple-point fuel injection systems. The advanced carbureted systems include vaporizing chokes and carburetors, sonic carburetors, single point fuel injection systems, improved conventional carburetors and variable venturi carburetors. These advanced systems are all being investigated for their feedback control potential, and have promise to be integrated into electronic fuel metering systems for the future.

Another potential advance in the general area of air/fuel preparation but not specifically fuel metering has to do with air/fuel mixture mixing. A recent report in the automotive press* indicates that Ford of Europe has under development a sonic air/fuel mixing device that apparently may provide some improvements. The mixing device apparently is placed between the carburetor and the intake valve. NOx reductions of 80 percent, HC reductions of 17 percent and the "virtual elimination" of CO were reported. Fuel economy was also said to be improved. Unfortunately, the baseline and the test procedure were not reported. In addition, technology that may be considered "advanced" in Europe sometimes is not so advanced when compared to domestic technology. Nevertheless, this approach is an example of the benefits that could be derived from improved air/fuel mixture dispersion and distribution. This approach may also have benefits in systems that use EGR, to improve the EGR distribution, and hence, EGR tolerance.

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* Automotive News, March 22, 1976.

An additional advantage of any advanced fuel metering technique when used with feedback control is that the systems tend to be self compensating for barometric pressure fluctuations. This has high altitude emission control benefit implications. Automatic compensation for barometric pressure changes also seems to be a technique superior to the recalibration changes that most manufacturers have chosen for high altitude compensation. When cars calibrated to meet the emission standards at high altitude are driven at low altitude some systems may be operating too lean with undesirable driveability, performance, and emission characteristics. True barometric pressure compensation would solve this problem.

The range over which barometric pressure changes can affect emissions may also be less than the range from sea level to Denver, for systems meeting low CO levels. As the CO emissions become lower, more subtle changes in barometric pressure may influence CO emissions. At least one manufacturer believes that this may be the case, and if it is, barometric compensation might be needed to control emissions to the desired levels even at low altitude, because the day-to-day barometric pressure fluctuations might influence the emissions. EPA is studying this issue to determine if it is a true effect or due to lab-to-lab correlation problems.

If systems can be developed that do not obsolete much of the current production tooling, the lead time and cost implications for early production introduction are favorable. Also, lower cost systems could be available sooner. If fuel injection is used the lead time will be longer. Reports in the news media* indicate that Bendix is building a new facility to build injectors. This facility is planned to be on stream in mid-1977, and will eventually produce 2.4 million injectors per year. Assuming an average of six injectors per vehicle, this implies only about 400,000 vehicles could be supplied from this new source, probably only for the 1978 model year. Of course, there are other injector plants overseas, but their production may not be available for use in domestic automobiles.

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* The Ann Arbor News, February 4, 1976.

A Lead-Tolerant Catalyst?

DuPont has developed a catalyst which appears to be somewhat resistant to poisoning by lead. Briefly, the catalyst is a perovskite-based catalyst in which some of the active materials are held in a lattice in such a way that lead cannot easily poison them. The catalyst can be formulated as an oxidation, reduction, or 3-way catalyst. Some of the positive points of this catalyst type are said to be its thermal stability at high temperatures, high activity, and resistance to poisoning. However, they need to be run somewhat hotter than more conventional oxidation catalysts, and tests run to date (by Chrysler, for example) show relatively low HC efficiency.

Although such catalysts have been investigated to permit the use of leaded fuels some uses of this catalyst type that are compatible for both leaded and unleaded fuel are worthy of mention. First, if the temperature capabilities are significantly better than current catalysts they could be used as start catalysts or as a manifold-mounted (inside the exhaust manifold) oxidation catalyst. Good resistance to high temperatures and poisoning is required of this type of system which has great potential for helping solve the HC warm-up problem. Second, this catalyst type could be used as a 3-way or a NOx catalyst. In fact, if the stabilizing properties of the lattice are good enough to prevent ruthenium (Ru) from being lost, this could be a significant advance in NOx catalyst technology, because Ru is an excellent NOx catalyst material that has defied successful stabilization in an active form to date. (It tends to form a volatile and toxic oxide.) NOx catalysts also need high temperature stability, so the perovskite catalyst may find its best application as a NOx catalyst. Of course, more testing is needed to more properly assess the potential of this promising new technology.

Because of potential industry interest in lead-tolerant catalysts,data from two automobile manufacturers on the effect of lead on HC emissions should be mentioned. GM and Honda reported data on the effects of leaded fuel on HC emissions at no accumulated mileage. That is, the results reported were not a durability effect, they are a combustion effect. The results are shown in Table 2-2.

Table 2-2

Effect of Leaded Fuel
on HC Emissions
(no accumulated miles)

Source	Fuels	% Reduction in HC (1)
GM	1.5 gr/gal leaded	28
	1.0 gr/gal leaded	23
	0.5 gr/gal leaded	9
Honda	3.15 gr/gal leaded	20

(1) % reduction in HC attributable to removal of lead from fuel.

According to GM, the lead acts as an HC oxidation inhibitor. This data along with the now recognized* lack of improvement in fuel economy as compression ratio is raised, if emissions are held constant, might suggest less manufacturer interest in lead-tolerant catalysts.

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* Emission Control with Lean Mixtures by J. E. Schweikert et. al., SAE Paper 760226, presented at the Automotive Engineering Congress and Exposition, Detroit, Michigan, February 1976.

Also, more interest is being directed toward Ethyl's MMT (methylcyclopentadienyl manganese tricarbonyl) additive, which also has antiknock properties. Because of its not yet precisely defined effect on catalyst HC conversion efficiency (CO activity does not appear to be harmed), but more because it is not yet absolutely certain that this manganese compound and its combustion products are benign, it is difficult to make projections for widespread MMT use, although it probably is a tempting octane booster for those refiners lacking a little bit of octane to get to 91 RON, or for those who desire to increase their octane to increase customer satisfaction.

More Interest in Diesels

The Diesel engine for light duty use has received increased interest and emphasis in the last year.

Two manufacturers, Daimler-Benz and Peugeot, currently market Diesel engined passenger automobiles in this country. However, the significant trend is that other manufacturers are exploring the possibility of light duty Diesel use, with the potential that the number of Diesel powered light duty (automobile and/or light duty truck) applications may increase. Important work is being conducted by Volkswagen and GM. Toyota, Nissan, Isuzu, Fiat, Ford, Chrysler, Hino, Mitsubishi, Yamaha and others* are also investigating Diesel technology for light duty applications.

Most of the work being conducted to date has been the application of current Diesel technology to the light duty vehicle applications, and/or making minor modifications to existing technology. While this approach is a first step, the real work that needs to be done on Diesels, i.e. advanced NOx, smoke, HC, CO, and odor control concurrent with improved specific power output, is not being pursued vigorously.

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* Opel is not included since, according to published reports, Opel automobiles will not be imported by GM after model year 1976.

There has been much debate over the potential of the Diesel to meet low emission standards, especially low NOx standards. Some of the data in Diesels at NOx levels around 1.0 NOx is shown in Table 2-3.

Table 2-3 indicates that Diesel vehicle tests results at or below 1.0 NOx have been achieved. In most cases, HC levels were over the 0.41 HC level. It should be pointed out that some of the vehicles were essentially uncontrolled for HC, CO and NOx. There are no vehicles in Table 2-3 that had inertia weight greater than 4000 lb. Because DF's for Diesels are typically low (about 1.0 or lower) the data in Table 2-3 indicate that Diesels could meet 0.41 HC, 3.4 CO, 1.0 NOx standards in vehicles at least as heavy as 4000 pounds inertia weight.

The issue of achieving NOx levels lower than 1.0 for the Diesel is one of the most controversial areas in the Diesel vehicle emission control field. Extensive emission control work is needed to resolve this issue. Certainly more work on advanced EGR systems is going to be required as a first step. Daimler-Benz's tests below the 0.41 HC, 3.4 CO, 0.4 NOx levels, reported in 1973, were obtained with EGR, so this is a logical step. The EGR systems will probably have to be sophisticated recirculating EGR modulated as a function of speed and load. Controls as sophisticated as feedback control of EGR may be needed, and are not impossible with the advances made recently in measuring exhaust gas O_2 levels in lean regimes*. Concurrent with the EGR work, of course, should go more work on HC control, since HC emissions tend to be increased with EGR. Improved injection systems are the obvious first step here. The same heat conservation technology that is being investigated for gasoline engines, i.e., low conductivity coatings, may have applicability to Diesels too. Spraying the combustion chamber with a

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* CoO Sensors for Measurement and Control of Exhaust from Lean Burn Engines, by G. L. Beaudoin, et. al., SAE Paper 760312, presented at the Automotive Engineering Congress and Exposition, Detroit, Michigan, February, 1976.

Table 2-3

Recent Test Data From Diesel Vehicles With NOx levels About 1.0 NOx

Vehicle	Inertia Weight	HC	CO	NOx	Urban MPG	"Highway" MPG	Fuel	Comments
Peugeot 504	3500	0.42	1.43	0.95	27.1	35.2	ID	1976 Official Certification results, including DF.
Peugeot 504	3500	0.61	1.60	0.95	26.4	34.1	ID	
Peugeot 504	3500	0.43	1.55	1.01	27.1	35.4	ID	
Peugeot 504	3500	0.60	1.47	1.16	26.7	33.4	ID	
Peugeot 204	2500	1.60	2.75	0.69	33.0	40.9	2D	Low mileage EPA test of vehicle not imported into the U.S. Emissions essentially uncontrolled.
VW Diesel Rabbit	2250	0.19	0.98	1.19	37.2	48.2	2D	Low mileage EPA tests of a prototype vehicle
VW Diesel Rabbit	2250	0.13	0.64	0.94	43.0	60.2	N.A.	Results from VW status report from a test with an unspecified injection system. Low mileage is assumed.
Wilcap Pinto	2750	0.54	1.13	0.75	46.1	60.2	2D	EPA tests of a Nissan CN-4-33 retrofitted into a 1971 Ford Pinto. "Highway" fuel economy values w/o overdrive. Vehicle essentially uncontrolled for emissions.
Toyota Land Cruiser	4000	0.3-0.4	1.5-2.0	0.9-1.0	25-27	N.A.	Japanese Industrial Standard	Prototype vehicle. Low mileage tests. Engine modifications calibrations and gear ratio changes. Fuel economy is 18% better than the production version at 3.5 to 4.5 NOx.

coating might help HC emissions, smoke control, and ignition delay. Spraying the inside of a swirl chamber or a prechamber might additionally help the divided chamber (or indirect injection, IDI) engine used in light duty applications more nearly approach the fuel consumption characteristics of a direct injection (DI) engine.* Potential benefits in reduced heat rejection to the coolant are also possible.

Other areas that need to be investigated more thoroughly include low and variable compression ratio approaches.

In summary, the capability of Diesel engined vehicles above 4000 pounds IW to meet NOx levels of 1.0, and the capability of any Diesel engined vehicle to meet 0.4 NOx, cannot be defined at this time. Much work remains to be done to meet low NOx levels, particularly for the heavier vehicles. Much of the current controversy over the Diesel is likely due to the contentions of those who want the low NOx standards deferred on basis of the argument that the Diesel will be eliminated at low NOx levels and it's fuel economy benefits lost. However, the purported NOx level that will "foreclose" the Diesel has varied in the past, starting at about 2.0 NOx or higher for all cars, then going to 1.5 NOx, now it is closer to or at 1.0 NOx for 4000 pound and below vehicles.**

Nevertheless meeting 0.4 NOx, especially in heavier Diesel vehicles, will be a difficult task, if it is at all possible. It is premature to make strong conclusions one way or another since making these conclusions would be based on old or contemporary technology or on a lack of effort in important R&D areas.

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* The gap in BSFC between IDI and DI engines is not as wide as some might think. DI proponents rarely compare the BSFC's on a constant emissions basis. On this basis the IDI is closer. Reducing heat transfer out of the prechamber will close this gap even further. Pumping losses in and out of the prechamber still remain, so it is not known if the BSFC or fuel economy will be greater for the IDI engine or not, at constant emissions.

** Approaches to Low emission Levels to Light-Duty Diesel Vehicles by M. Amano, et. al, SAE Paper 760211 presented at the Automotive Engineering Congress and Exposition, Detroit, MI, February, 1976.

It must also be noted that while NOx control is a difficult task for the Diesel, it may not be the major problem area. Especially at low NOx levels, improvement of smoke, odor, starting and performance characteristics may be as great a development problem.*

Another potential emission control problem that could be tougher than NOx to solve is particulates, including but not limited to, sulfuric acid. So long as there remain uncertainties regarding the need for control of all kinds of particulate emissions from mobile sources from a health effects point of view, manufacturers may be reluctant to expend effort on Light-Duty Diesels.

NOx Reduction Without a NOx Catalyst?

Under the correct conditions NOx and HC can chemically react with each other in the gas phase to reduce NOx without a NOx catalyst being present. Significant NOx control, well over 80% in some modes, has been reported**.***

The work done to date has centered around the addition of a hydrocarbon material to the exhaust gases to promote the reactions. The temperatures needed for high NOx conversion efficiencies are higher than most catalysts operate at now. Under some conditions HCN may be formed, but as indicated in the GM Status Report, oxidation catalysts are effective in controlling HCN. An oxidation catalyst or thermal reactor would be needed downstream of the gas-phase NOx reduction chamber (which could be like a thermal reactor). The oxidation catalyst (or a 3-way catalyst) would be needed to oxidize HC and CO.

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* Although the Diesel Rabbit is a good example of what can be done by adapting well-known existing Diesel technology.

** The Reduction of Nitric Oxide in Simulated Combustion Effluents by Hydrocarbon-Oxygen Mixtures by A. L. Meyerson, Reprinted from the Fifteenth Symposium (international) on Combustion at the Toshi Center Hall, Tokyo, Japan, August, 1974.

*** Exhaust-Port Fuel Injection for Chemical Reduction of Nitric Oxide by D. J. Pozniak, SAE Paper 750173, presented at Cobo Hall, Detroit, MI February, 1975.

This type of approach may have promise as an attractive NOx control technique.

One way in which this might be done is by dumping fuel into the exhaust manifold, a somewhat less than desirable approach. However the hydrocarbon needed could also be provided by the engine, i.e. it may be possible to calibrate the engine for the appropriate amount of hydrocarbon emissions (engine-out) which could correspond to a desirable fuel economy calibration for some engines.

The major problem that is foreseen for a system that uses the homogeneous gas phase reduction of NOx is operating temperature. The results reported to date have been performed at temperatures somewhat in excess of those common in conventional exhaust manifolds, and spark retard was used in one case to obtain the exhaust gas temperatures needed. Spark retard is counter to the desire for improved fuel economy. It appears that extensive heat conservation techniques may be required to make the approach attractive from the standpoint of fuel economy. The reducing agents that are thought to produce the NOx reduction may also be produced in engines operating with lower exhaust gas temperatures, but to date there has been little reported that would indicate the extent of the NOx reductions possible with a system on a vehicle, with heat conservation techniques, the use of engine-out HC as the source of HC, and post-reactor oxidation control.

SECTION 3

ALLOCATION OF THE BENEFITS OF IMPROVED TECHNOLOGY AMONG DIFFERENT OBJECTIVES

3.1 Why All Vehicles are not the Same

Vehicles sold today are of many different types, with widely varying characteristics. The reason is, of course, that manufacturers see a market demand for a variety of vehicles.

There are many design and performance parameters that are important for vehicle design. Some of these are listed below in Table 3-1.

Table 3-1

Some Vehicle Design and Performance Characteristics

Cost
Styling
Convenience features
Roominess
Safety performance
Stopping performance
Ride Comfort
Reliability/maintainability
Fuel compatibility
Manufacturability
Use of critical materials
Fuel economy
Performance
Driveability
Exhaust emissions
Engine durability
Durability/corrosion resistance
Handling performance
Ease of entry/exit
Noise/vibration/harshness
Passenger carrying capacity
Luggage/load carrying capacity

These parameters must all be balanced against one another to arrive at the final vehicle design. The relative importance placed on the various parameters determine what the resulting design will be like.

The vehicle will reflect the emphasis put on the design and performance parameters. It will be a better performer in the areas to which high priority has been given, and perhaps less so in the areas given less priority.

3.2 How Emphasis on Selected Parameters Can Influence the final Product

The emphasis given to the various parameters is determined partially by the automobile companies and partly by the Government regulations. Safety, emissions, and more recently, fuel economy are requirements for which Federal standards exist.

Looking at today's vehicles, it is obvious that although they all meet the safety and emission standards, they represent a wide range of vehicle types with different characteristics in the other areas. These differences are not just happenstance. They result from different emphasis given to the various items listed in Table 3-1. This emphasis is determined by the automobile manufacturers. They choose the types of vehicles to market and give different emphasis to different vehicles in their model lines in a manner calculated to maximize income and profits, usually but not always, by maximizing sales.

Designers strive to obtain the best rating for their vehicles in all of the Table 3-1 categories. However some of the desirable properties are difficult to achieve simultaneously. For example if the highest priority is given to making the vehicle carry a large number of passengers (say up to 12) and/or carry large, bulky cargo, the vehicle could wind up being a van-type vehicle. Such a vehicle may not be the most desirable one from the stylist's standpoint. This is one example of a tradeoff where in order to meet a criterion given high priority, some compromises in other areas must be made.

These tradeoffs occur during the entire concept, design, development and testing process that leads up to actually producing the vehicle. The emphasis in given areas can change during the development process, in order to meet perceived or predicted production and market pressures.

The relationship between exhaust emissions and fuel economy is one area in which discussion has been extensive and one in which much apparent controversy exists.

In a previous report* the relationship was discussed at length. The salient points were, and remain:

1. For a fixed technology and cost, at a given point in time, a relationship exists between exhaust emissions and fuel economy.

2. Improved technology, which takes time and effort to develop, and may be more costly, can change the relationship from what had existed in the past.

3. Based on 1 and 2 above there is no fundamental relationship between exhaust emissions and fuel economy.

This is a special case of the relationship between two of the performance parameters in Table 3-1.

3.3 Some Examples of Difference in Emphasis

For illustration it is useful to include only those parameters from Table 3-1 that are affected to any great degree by emission controls. These areas are:

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* Automobile Emission Control - The Technical Status and Outlooks As of December 1974.

Table 3-2

Areas Influenced by Emission Control

1. Cost (emission control system cost)
2. Performance
3. Driveability
4. Exhaust Emissions
5. Fuel Economy (due to engine effects)
6. Maintainability
7. Manufacturability
8. Use of Critical Materials
9. Fuel Compatability

In the following examples the discussion centers on the various ways in which improved technology could be used.

Example 1 - Oxidation Catalysts

This example is the most well-known. The use of oxidation catalyst technology in model years 1975 and 1976 permitted the benefits of this technology to be traded between the emission control and fuel economy areas. By far most of the benefits were taken in fuel economy. Non-catalytic systems could have been used at the 1.5 HC, 15 CO, 3.1 NOx levels. The oxidation catalyst systems, originally developed to meet the old (original) 0.41 HC, 3.4 CO, 3.1 NOx 1975 standards, had the capability to be recalibrated for the less stringent levels with the benefits taken in the improved fuel economy shown by the 1975 and 1976 models.

Example 1 is history, showing how the benefits of an improvement in technology were used by the industry. Other technological improvements, now in the research and/or development stage, may have benefits that could be used in several areas. Some of these technological improvements are discussed in the following examples.

Example 2 - Improved Oxidation Catalysts

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Improved oxidation catalysts are used here as an example of improved aftertreatment efficiency, which could be thermal, catalytic or a combination of both. The oxidation catalysts used for model year 1975 had a 50,000 mile conversion efficiency of about 50 percent for HC and CO. Improved oxidation catalysts, which were being developed for the now-suspended 0.41 HC, 3.4 CO, 2.0 NOx 1977 standards, and are continually being developed further, showed 70 percent conversion efficiencies for HC and CO. How could the benefits of this improvement be used?

a. With no changes in calibrations, emission levels of about 40% lower HC and CO could be attained, with no change in fuel economy.

b. Emission levels between the levels obtainable with the 1975 catalyst and the levels discussed in a) above could be attained with improved fuel economy, if the calibrations for HC control on the 1975 models with the 1975 catalysts was not optimum.

c. At the same emission levels that the 1975 models met, further recalibration beyond that of case b) above might be possible, if other problems such as octane requirement do not arise.

d. Part-throttle fuel metering might be enriched for better driveability at the same emission level. Performance could also be enhanced by this technique, along with ignition system recalibrations.

e. Cost might be reduced due to the deletion of auxiliary devices such as transmission controlled spark (TCS). If the catalyst improvement involved better dispersion a lesser amount of active material might be used with cost reduction and critical material use benefits.

f. If a manufacturer needed a catalyst change to meet the 1975/1976 standards, the use of the improved catalyst might lead to not needing one, with benefits in maintainability and service cost.

Example 3 - Fuel Injection

Fuel injection is used here as an example of improved fuel metering which could be improved carburetion, single point fuel injection or the more conventional electronic or mechanical fuel injection systems. Fuel injection can provide better cylinder-to-cylinder fuel distribution and offers promise for more precise fuel metering. It is a key element in many advanced control concepts, especially those that use 3-way catalysts, although carburetor development is underway to reduce the advantages that fuel injection has. How could the benefits of fuel injection be used?

a. Vehicle performance might be improved. This is the route that was taken by the domestic manufacturers in the 1950's when Chrysler, GM and AMC used fuel injection on a small number of models. This is the approach taken by GM on the 500 cid Cadillac currently.* Torque is up from 360 to 400 ft-lb, and power was increased from 190 to 215 HP.

b. Driveability, especially in the cold start, warm-up, and response areas, might be improved by the use of fuel injection. This is apparently the major benefit seen for fuel injection currently.*

c. Fuel economy might be improved. The fuel injection benefits as used on the Seville are reported to be improved fuel economy.*

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* "Cadillac's Electronic Fuel Injection" by Larry Givens, in Automotive Engineering, February 1976.

d. Exhaust emissions might be lowered. HC benefits are possible with fuel shutoff on deceleration, CO benefits may accrue due to better cylinder-to-cylinder control. The leanest cylinder on conventional systems determines the air/fuel ratio, and on many systems the other cylinders are running too rich. NOx benefits are possible* since fuel injected engines may have higher EGR tolerance.

Fuel injection's precise fuel metering, when incorporated into a feedback control system may permit use of the 3-way catalyst, considered an attractive future control system.

e. The requirements on the fuel used in terms of starting and other characteristics may be less stringent with fuel injection.

Example 4 - Improved Warm-up Systems

One of, if not the most important areas of investigation for improved emission control is during the "cold start" (Bag 1) phase of the emission test. Most of the emissions of HC and CO come from this part of the test. Systems have been and are under development to improve warm-up. These include EFE and super EFE, start catalysts, improved insulation (port liners, insulated manifolds, etc.) heated fuel injection nozzles, new chokes, (for example, electric vaporizing chokes) and lower thermal inertia main catalysts, e.g. a switch from a pellet to a monolith. All of the approaches improve warm-up characteristics. How could this benefit be used?

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* "Cadillac's Electronic Fuel Injection" by Larry Givens, in Automotive Engineering, February 1976.

a. Vehicle driveability after start-up and during warm-up could be improved. GM, for example, has always maintained that their EFE system is a driveability improvement device.

b. Lower HC and CO emissions could be obtained. If the choke can be removed sooner and the fuel metering can attain its warmed-up air/fuel ratio more quickly, some HC and CO benefits can be expected.

c. If the approach results in much improved emissions, cost reductions in some other areas of the emission control system may be achieved.

d. If the system without the improved warm-up characteristics used less than optimum calibrations from the fuel economy standpoint (e.g. massive retard to get the catalyst to light-off quickly), some fuel economy benefits, over and above those attendant with running with less cold enrichment, may be possible.

e. If the system can warm-up the inducted air/fuel mixture well enough some of the volatility demands on the fuel might be reduced.

Example 5 - Electronic Controls

Systems to electronically control spark-timing, EGR, air/fuel ratio, transmission shift points and other engine parameters are now under active development. The control of the engine parameters will be provided by an electronic control unit which may receive input from several on-board sensors. The controls may be more precise, faster, and sophisticated than current systems. For example the spark timing could be whatever is desired, not subject to the limitations of current mechanical and vacuum advance systems. How could these potential benefits be used?

a. Fuel economy could be improved, by allowing engine calibrations to more closely approach the optimum on a transient basis.

b. Emission control performance could possibly be improved via an optimization strategy similar to that of a) above in which emissions are given consideration.

c. Performance and driveability could be improved through better and faster air/fuel ratio control, especially in transients.

d. Maintainability could be improved, since such systems could be compatible with electronic diagnostic techniques which offer the potential for quicker and more accurate problem diagnosis and solution identification.

Example 6 - Improved EGR Systems

As more has been learned about NOx control through EGR and its impacts on driveability and HC emissions, the desirability of a sophisticated EGR system that would modulate the flow of EGR in a way better than even the best current systems has increased. Although this sytem could be a part of the Electronic Control System, Example 5, this EGR is treated separately, since the potential benefits serve as a good example, and the approach need not be electronic. How could these benefits be used?

a. Improved NOx control (i.e. lower NOx) could be achieved by controlling NOx well in those modes where it is a problem. HC benefits could also result.

b. Vehicle driveability could be improved by adjusting the NOx control to provide the EGR rate needed to keep NOx constant with improved driveability.

c. If the NOx control can be achieved with the advanced system at the same NOx level that the less sophisticated system had, and there is an HC benefit the spark control might be recalibrated for better fuel economy.

Example 7 - Improved Transmissions

Transmissions have been used in the past as part of the emission control system by having the transmission gear control the amount of spark advance. Similar systems may be used to control the air pump for sulfuric acid control. The major new effort now in transmissions is toward more gear ratios and lock-up of the torque converter for conventional transmissions, and research and development into continuously variable transmissions (CVT's) which may offer even more potential to allow the engine to run closer to the desired condition. How could the benefits of this type of technology be used?

a. Improved fuel economy might result from engine operation at higher BMEP and lower speed, compared to today's practice.

b. Performance may be improved if the torque-speed characteristics of the improved transmissions are superior to those of current types.

c. There may be some potential for reduced exhaust emissions. Computer projections* (not vehicle data) indicate that, given the addition of an extra gear (3 speed to 4 speed) in an automatic transmission and torque converter lockup at a speed ratio of unity or lower, predicted NOx emissions were lower by about 30 percent. The predicted effect on fuel economy was a gain of 15 percent.

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* Simulated Sensitivities of Auto Fuel Economy, Performance and Emissions SAE Paper 760157 by A. C. Mallarias, et. al., presented at the SAE Congress Detroit, Michigan, February 1976.

Example 8 - Weight Reduction

The domestic automobile manufacturers are now embarked on ambitious weight reduction programs that are expected to result in vehicles being produced in the near future that are significantly lighter for the same room inside than are today's vehicles. How could this improvement be used?

a. Fuel economy could be improved. Vehicle weight is an important parameter in determining a vehicle's fuel economy and reductions in weight can be expected to improve fuel economy. Since, in general, heavier vehicles are more difficult to control for mass emissions due to their greater exhaust volumes per mile, engine recalibrations may permit additional fuel economy gains at the same emission level with the same control systems.

b. Because of the reduction in exhaust volumes, emission control may be improved, especially for NOx.

c. Given a lighter weight vehicle, if the installed horsepower is not changed, performance would be expected to improve.

d. Depending on the rate at which the new tooling is amortized, and on the extent of more costly materials used on the lighter weight vehicles, some cost reduction may be possible, since the vehicles will require less raw materials. The partial easing of the emission control burden may permit additional costs to be taken out of the emission control system, at constant emissions.

Example 9 - Improved Ignition Systems

Improved ignition systems, some of which are under development, and some of which are in production, can provide more positive ignition of diluted mixtures via increased spark energy and longer spark duration, and may have beneficial implications in spark plug life. How can these benefits be used?

a. If the dilute mixture is a leaner one, some fuel economy benefits may be possible, through extension of the lean limit.

b. Spark plug life, (especially with unleaded fuel) may be lengthened, with an improvement in maintainability. In addition benefits accure from elimination of points and condenser maintenance for some systems.

c. Emissions may be improved due to the ability to increase the lean limit, and the capability to fire mixtures diluted with EGR, not excess air, may also be improved.

Example 10 - Reduced Contaminant Fuels

Fuels available for the 1975 and 1976 vehicles have low lead and phosphorus levels. The levels in the field are low enough that EPA has reduced the fuel contaminant levels permitted in certification mileage accumulation fuel to levels even lower than those permitted in the unleaded fuels for model year 1975 certification. How could this potential benefit be used?

a. Improved emission control, especially for HC may be achieved, comparing leaded fuel to unleaded fuel. This is because HC performance on a given test and the HC DF, even in a non catalyst system, are somewhat better when unleaded fuel is used. The new certification fuel could result in lower HC and CO emissions compared to the earlier unleaded fuel all by itself with no system changes.

b. Fuel economy might be improved with either unleaded compared to leaded fuel (at the same compression ratio), or with the new certification fuel compared to the older fuel if any HC benefit is used to permit more spark advance.

c. Unleaded fuel may result in longer spark plug life and reduced EGR system maintenance, which could translate into maintainability and service cost benefits.

d. The new certification unleaded fuel compared to the older unleaded fuel may permit some cost to be taken out of the control system (e.g. lower noble metal loadings) at constant emissions, with cost and critical material usage benefits.

Other Examples

There are other examples not covered in the above discussion, such as variable valve timing (potential benefits possible in performance, or fuel economy, or emissions (controlled internal EGR)) and turbocharging (potential benefits in performance or fuel economy at constant performance). In fact, almost every area in which engine and emission research and development work is being conducted could be used as examples.

3.4 Summary

The point to the above examples is that there are usually several ways in which the benefits of advanced technology can be allocated among different goals. Benefits taken in some of the areas may reduce the benefits possible in other areas while some areas may benefit together.

Usually, not all of the entire benefit is taken in one area, but rather apportioned to meet the specific goals and design targets of the manufacturer. The areas in Table 3-2 (fuel economy, driveability, etc.) are traded off both among themselves and against the areas in Table 3-1 (vehicle-related areas) to arrive at the final product.

The manufacturers determine, to the largest degree, how the benefits are to be apportioned. Their major goal must be to sell automobiles. Of all of the areas listed in Table 3-2, improvements in every area save one may be expected to increase the sales potential of vehicles. The only area in which improved performance does not increase sales potential is in exhaust emissions, primarily because improved emissions performance is not of immediate interest to most individual car buyers.

A primary reason for the current controversy over the relationship of exhaust emissions standards to fuel economy is that fuel economy helps sell cars, whereas low exhaust emissions do not. Most manufacturers would like to be able to take the benefits of improved technology for purposes other than lower emissions. That is why manufacturers, classify some examples of improved technology as "fuel economy devices" or "driveability improvers". Since they have made the decision to take the benefits in this area. For example, GM originally did not submit any data in their Status Report on the emissions performance of vehicles equipped with electronic spark timing, because, according to GM, it is a fuel economy device that has nothing to do with emissions.

The EPA's analytic approach is somewhat different. EPA has in the past pointed out the potential benefits that could be attained if the benefits are taken with the emphasis directed toward improved exhaust emission performance and good fuel economy. It is this basic difference in analytic approach that gives rise to controversy concerning the effects of emission controls on future vehicles, especially in the areas of driveability and fuel economy.

SECTION 4

FUEL ECONOMY AND COST

4.1 Introduction

This section discusses fuel economy and cost, with the emphasis on those aspects of fuel economy and cost that are the most directly related to emission controls.

The potential fuel economy of the 1977 models based upon preliminary data and directional trends is discussed first, then some aspects of the fuel economy performance of 1975 and 1976 cars is discussed and then the fuel economy of future vehicles is discussed, followed by the cost section.

4.2 Fuel Economy Potential of the 1977 Models

A precise description of the fuel economy performance of the 1977 models cannot be available until 1977 certification is complete in late summer, 1976. However, there are some directional trends that influence the fuel economy of the 1977 models positively. This discussion will focus on potential fuel economy and should not be interpreted to represent a prediction because, as was pointed out in Section 3, the emphasis that the manufacturers give to areas other than fuel economy or emissions can influence the results.

Of the many influences the most important are the revised certification fuel specifications, the emission standards, improvements in emission control systems, and new vehicle technology.

The revised certification fuel specifications will allow benefits in reduced DF which can be translated into a fuel economy benefit. New vehicle technology which will first appear in model year 1977 is reflected in the redesign of some models by some manufacturers. These new body designs are expected to be lighter in weight with concommitant favorable fuel economy and emission control implications.

For the Federal 1977 vehicles, the emission standards for HC and CO are unchanged, but the NOx standard is reduced from 3.1 NOx to 2.0 NOx. This change need not have a negative impact on fuel economy. Some negative impact on fuel economy could be expected if spark retard were resorted to as the only or primary means of reducing NOx but with the more widespread use of proportional EGR systems and larger and/or improved catalysts planned for use by many manufacturers the change in NOx can be made without resorting to massive spark retard. The control of NOx with EGR would be expected to raise HC levels if the older-type non-proportional systems were used, but the better EGR systems should reduce this effect. Even if there is some increase in engine-out HC, most manufacturers who use oxidation catalysts have sufficient cushion at the current 1.5 HC level that they should encounter no difficulty.

On balance, the directionally positive fuel economy trends for the 1977 Federal vehicles lead to the conclusion that there is every reason to expect that the 1977 Federal vehicles could be as good or better than the 1976 Federal vehicles in fuel economy.

For the 1977 California vehicles the standards change from 0.9 HC, 9.0 CO, 2.0 NOx to 0.41 HC, 9.0 CO, 1.5 NOx. In their status reports to EPA, the domestic manufacturers made the fuel economy estimates for their 1977 California vehicles as shown in Table 4-1.

Subsequent to the presentation of the above estimates to EPA, a public meeting was held by the California Air Resources Board (CARB) to discuss the estimated fuel economy performance of the 1977 California models. In addition to the exhaust emission standards, California at that time was considering adjusting their assembly line test procedure and allowing a methane allowance for hydrocarbon emissions. The estimates made by the manufacturers to CARB on February 20, 1976 are summarized below in Table 4.2.

Table 4-1

Fuel Economy Impacts of the
1977 California Emission Standards
(Manufacturer's Estimates Made to EPA)

Manufacturer	Fuel Economy Impact	Base
AMC	No specific estimate (1)	
Chrysler	16 percent loss	1976 Federal
Ford	No specific estimate (2)	
GM	20-30 percent loss	"What otherwise could be accomplished at the 1975-76 Federal standards"

(1) AMC was not sure that they could meet the emission standards.

(2) Ford earlier reported to EPA (January 14, 1975) that a conventional oxidation catalyst system would be about 23% worse in fuel economy at 0.41 HC, 3.4 CO, 2.0 NOx than the same system at 1.5 HC, 15.0 CO, 3.1 NOx.

Table 4-2

Fuel Economy Impacts of the
1977 California Emission Standards
(Manufacturer's Estimates Made to CARB)

Manufacturer	Percent Change in going from 0.9 HC, 9.0 CO, 2.0 NOx to 0.41 HC, 9.0 CO, 1.5 NOx only	Percent change due to all changes 77 vs 76	Base
AMC	-	-	-
Ford	5 to 7 percent loss	3 to 5 percent gain	76 Cal
Chrysler	0 to 4 percent loss	0 to 4 percent loss	76 Cal
GM	7to 8 percent loss	3 percent gain	76 Cal

There are several possible explanations for the discrepancy in the Tables. The fuel economy bases for comparison are different. The estimates made earlier to EPA could also have been based on older assumptions about the details of the California regulations that since may have changed.

The actual fuel economy performance of the 1977 California vehicles will depend to a great extent on the emission control systems actually used. Currently some manufacturers are certifying more than one type of system for 1977 California. As has always been the case, not all of the systems are carried through to final certification by a manufacturer, and even then, if more than one system is certified, the manufacturer can use one or more of the certified configurations at his discretion. For some manufacturers the California market may not be large enough to justify the development and building completely different systems, and thus the manufacturer may try to meet the California standards with just a recalibrated Federal system. The development, and production costs would tend to be lower even though the fuel economy might tend to be worse. Other manufacturers may have incentive to have an attractive vehicle for California in 1977, and thus use improved systems that were under development for the original 1977 0.41 HC, 3.4 CO, 2.0 NOx Federal standards*.

As of the time of this writing what is happening appears to be a combination of both approaches. Chrysler and AMC appear to be concentrating on the improved systems approach, GM seems to be leaning toward the recalibration approach, and Ford seems to be somewhere in between.

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* These standards were suspended for one year by the EPA Administrator on March 5, 1975. The current 1977 Federal Standards are 1.5 HC, 15 CO, 2.0 NOx.

4.3 Update of the 75/76 Fuel Economy Performance

The latest estimates for the sales-weighted fuel economy of most of the manufacturers in 1975 and 1976 are shown below in Table 4-3.

These estimates, based on projected sales, can be compared to the fuel economy standards recently exacted. This is shown on Table 4-4.

Table 4-4
Manufacturers Not Now
Meeting Fuel Economy Standards
Set for Future Years

Year	Miles per Gallon Standard	Manufacturers Who Fall Below that Standard in 1976
1978	18.0	GM, Ford, Chrysler, Bricklin, Rolls-Royce, Checker
1979	19.0	The above plus AMC, Daimler-Benz, BMW
1980	20.0	The above plus Volvo
1985	27.5	All manufacturers except Fuji and Honda

Most of the gains in fuel economy by those companies that must make the greatest improvements from current levels will probably be obtained by the introduction of new smaller and lighter weight vehicles and/or lighter weight vehicles that are the same size as today's models, as is illustrated by the following case. If one computes the sales-weighted fuel economy from a production mix typical of manufacturers whose sales are dominated by heavier automobiles using typical 1975 fuel economy values the resultant composite sales-weighted fuel economy is about 15.5 miles per gallon. If the production mix were shifted around to be the mirror image of what

Table 4-3
Fuel Economy for Various Manufacturers

Manufacturer		1974	1975	1976	Manufacturer		1974	1975	1976
GM	Urban	10.54	13.49	14.50	Porsche	Urban	17.5	16.56	17.14
	Non-Urban	14.55	18.67	20.28		Non-Urban	27.3	25.89	26.90
	Composite	12.03	15.41	16.64		Composite	20.9	19.76	20.48
Ford		12.67	11.64	15.19	Bricklin		-	12.28	13.39
		18.62	17.11	20.96			-	16.62	17.77
		14.80	13.60	17.34				13.92	15.06
Chrysler		11.89	13.45	14.27	R.R.		8.2	9.03	10.03
		17.00	19.20	20.03			10.9	12.03	13.22
		13.75	15.54	16.39			9.2	10.17	11.25
AMC		14.46	16.77	16.15	A. Romeo		20.6	19.44	19.48
		19.52	22.57	21.83			26.8	25.26	26.90
		16.37	18.96	18.29			23.0	21.69	22.24
VW		22.61	23.04	22.95	Jaguar (BLMI)		9.4	10.95	10.83
		35.05	35.62	34.38			13.9	16.18	15.57
		26.91	27.39	26.98			11.0	12.81	12.55
Toyota		19.19	18.92	21.19	Renault		19.6	23.52	
		28.59	28.17	31.87			26.9	32.33	
		22.52	22.17	24.95			22.3	26.81	
Nissan		20.69	21.46	22.46	Peugeot		16.58	19.98	19.73
		30.00	31.09	31.87			23.05	27.51	26.23
		24.05	24.94	25.90			18.98	22.79	22.21
Volvo		16.55	16.35	16.45	BMW		16.69	15.45	16.52
		24.66	24.42	24.75			24.79	22.93	22.94
		19.42	19.21	19.37			19.54	18.11	18.90
Audi		19.14	20.33	21.89	Austin-MG(BLMI)		21.6	20.37	18.42
		29.67	31.58	30.83			30.2	28.60	31.87
		22.78	24.21	25.17			24.8	23.40	22.74
Fiat		18.89	19.00	19.45	Checker			14.90	15.70
		27.01	27.12	29.78				19.49	20.36
		21.85	21.96	23.05				16.70	17.50
Triumph(BLMI)		19.3	20.35	20.83			17.3	18.48	18.16
		27.7	29.22	29.44	BLMI		24.8	26.50	27.40
		22.3	23.57	23.98	All companies combined		20.1	21.39	21.41
Saab		18.41	21.15	20.00					
		21.91	25.23	27.59					
		19.84	22.81	22.82					
Fuji		22.5	23.20	26.46					
		31.0	32.11	35.02					
		25.7	26.51	29.73					
Daimler-Benz		13.30	15.03	16.32					
		18.76	21.25	22.52					
		15.30	17.35	18.63					
Honda		26.05	27.16	28.47					
		36.99	38.36	39.69					
		31.11	31.27	32.62					
Toyo Kogyo		11.69	14.36	18.93					
		17.07	20.97	27.19					
		13.62	16.73	21.93					

Production sales values used for 1974 whenever possible,
1975 and 1976 estimates based on estimated sales

happened in 1975, i.e., the production mix dominated by lighter weight vehicles, the sales-weighted fuel economy would be about 21 mpg. Such fleet-wide improvement would be achieved even without the individual vehicle improvement in fuel economy that was demonstrated in 1976 over the 1975 models.

This example shows the degree of improvement obtainable in sales-weighted fuel economy due to altering the production mix toward lighter weight automobiles. The trends in the industry in the design and development of new vehicles and new, more efficient, body designs for existing vehicles are all in the direction that should result in the production mix being significantly altered in the near term.

Another way to improve fuel economy is with development time and effort. Using the same production mix, the 1976 California vehicles are 4.6 percent better in fuel economy than the 1975 Federal vehicles. This shows that significant progress can be made in fuel economy even in only one year, even though the California vehicles meet more stringent emission standards.

4.4 Fuel Economy Projections for the Stringent Emission Standards

The projection of fuel economy for vehicles at more stringent emission standards involves the estimation of actual performance of advanced systems that have not yet been tested. Typical development vehicles tested to date have not had all of the components of what was termed in the past EPA reports to be a "full effort" system. A full effort system is defined as a system integrating most or all of the advanced components under development.

The methodology utilized in past EPA studies and reports to project the performance of "full effort" or reasonably selected technology has been to reduce the emissions of vehicles with less than full effort systems by a series of numerical factors. These factors reflect the emission reduction that has been demonstrated with the subsystems or components on engine dynamometer or on vehicles. The use of these adjustment factors by EPA in the past has been disputed by the automotive industry. However, the same approach will be taken in this fuel economy section. For the most part factors that reflect the use of technology that reduces HC emissions will be used. This is because HC is the single most important problem when one has to meet low emissions with good fuel economy.

The approach followed involves two basic steps: (1) estimating engine out HC emissions with the engine "optimized" for fuel economy and then (2) estimating the emission levels to which the HC emissions could be reduced by the application of emission control technology.

At this point a digression to discuss optimization and modeling is necessary.

As pointed out earlier in the discussion of all-electronic engine control, the biggest problem with the application of this technology is to determine just what the optimum calibrations really are. The flexibility inherent in the future electronically-controlled systems offers degrees of freedom not considered possible by engineers before, because of limitations of yesterday's and today's technology, but the full scope of the impact on fuel economy remains to be quantified.

Many have turned to computer modeling in an attempt to quantify the optimum calibrations. These models in general rely on brake specific emission and fuel consumption data determined by engine dynamometer tests. These data are combined with the calculated engine demands during the test to predict what the fuel economy and emissions would be on the EPA urban and/or non-urban test cycles. There are several basic deficiencies with this approach. The engine data are usually from hot (warmed-up) engines, operating at steady state conditions. Neither of these conditions is present on the emission test. The test cycle involves thermal transients and speed and load transients not comprehended by the models. This is important because the first few minutes of operation on EPA's cold start emission test may determine whether or not the vehicle will pass or fail, especially for HC and CO, and for any pollutant catalytically controlled. Thus this modeling approach can often lead to false or misleading fuel economy relationship.

In this report an effort has been made to rely as much as possible on vehicle results. The trends are clear. For the conventional engine, engine-out HC emissions at good fuel economy calibrations are higher than the 0.41 HC standard. Also, based on limited data obtained with current technology, HC emissions go up as NOx is lowered with EGR while retaining good fuel economy. The term good fuel economy rather than optimum fuel economy has been used since nobody really knows what the optimum fuel economy is.

A range is given on the HC values estimated below. This is because the details of the engine design that influence HC emissions from gasoline engines vary from engine to engine.

All of the variables that go into determining combustion chamber design, inlet and in-cylinder air flow, homogeneity and character of the air/fuel charge, and the details of the ignition system will influence the relationship. The estimates for engine-out HC emissions are presented below. Note that they are stated as "good" fuel economy calibrations not "optimum" fuel economy calibrations. The true optimum values could be higher or lower than those shown below.

Table 4-5
Engine-Out HC Emissions
for Good Fuel Economy
with No HC Emission Control

NOx Level grams per mile	HC Level (range) grams per mile
Totally uncontrolled	1.6 to 3.3
1.2 to 1.7 (1)	1.8 to 3.8
about 1.0 (2)	2.0 to 4.1

(1) Needed to meet standards of 1.5 to 2.0 NOx.

(2) Needed to meet standards of 1.0 or 0.4 NOx with additional NOx control via a catalyst.

As can be seen from Table 4-5 meeting 0.41 HC with good fuel economy presents the vehicle and engine designer with a significant challenge. Technical approaches for HC control considered by EPA to be reasonable are discussed below.

Improved oxidation catalysts and adjustments for the revised certification fuel specifications are the first steps. Oxidation catalysts with 70 percent HC efficiency at 50,000 miles have been demonstrated, using the previously specified certification fuel. The effect from the revised fuels specifications discussed in an earlier section is a reduction in 50,000 mile HC and CO emissions by factors of 0.742 and 0.767 respectively. Adjusting for the revised fuel and the improved catalysts yields 50,000 mile conversion efficiencies for HC and CO respectively of 78 and 80 percent. The combined factors then are shown below.

Table 4-6
New Certification Fuel Plus Improved Catalyst Factors

HC	CO	NOx
.22	.20	1.03

Future systems will have additional control technology. One of the more attractive techniques is heat conservation. Data on full heat conservation systems, such as, port liners, well insulated exhaust manifolds, and exhaust pipes with an oxidation catalyst are not available. However, as a surrogate to a full heat conservation system we have quantified the effect of exhaust port liners.

The effects of exhaust port liners can be found in the literature*. These data are shown below.

Table 4-7
Exhaust Port Liner Effect

System	HC	CO	NOx
without port liners	1.30	7.43	2.23
with port liners	0.52	6.79	1.85
Indicated Factor	0.40	0.91	0.83
without port liners	1.26	9.19	2.34
with port liners	0.98	7.10	2.20
Indicated Factor	0.78	0.77	0.94
Average of Factors	0.59	0.84	0.89

Undoubtedly the effect of port liners will vary from engine to engine due to differences in exhaust port area and length. EPA concludes that using the average of the factors is a good estimate of the effect.

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* Emissions, Fuel Economy and Durability of Lean Burn Systems by W.E. Adams, et. al., SAE Paper 760227, presented at the Automotive Engineering Congress and Exposition, Detroit, Michigan, February 1976.

As indicated earlier in the report the use of thermal and catalytic aftertreatment would be an attractive system for controlling emissions to low levels that may permit good fuel economy calibrations. Thermal reactors are one such thermal aftertreatment system.

The effect of a thermal reactor can be found in the above referenced paper (SAE 760227). This is shown in Table 4-8 as case 1. Other data was reported in the Ford Status Report. This is shown as case 2 in the table. The Ford results include the effect of port liners. Additional data can be found in the literature*, and is shown as case 3. In this case, two similar, but not identical vehicles are compared.

Table 4-8

Thermal Reactor Effect

Case 1	HC	CO	NOx
without reactor	1.26	9.19	2.34
with reactor	0.85	9.15	2.25
Indicated Factor	0.67	1.00	0.96
Case 2			
without reactor	2.10	16.90	2.40
with port liners plus reactor	1.14	13.40	1.74
Indicated Factor	0.54	0.79	0.73
Case 3			
without reactor	1.3	7.8	2.0
with reactor	0.62	4.8	1.7
Indicated Factor	0.48	0.62	0.85

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* Emission Control with Lean Mixtures by J.E. Schweikert, et. al., SAE Paper 760226, presented at the Automotive Engineering Congress and Exposition, Detroit, Michigan, February 1976.

Table 4-8 indicates that thermal reactor performance varies with design, particularly, if port liners are used. The average of the factors indicated, above for the two systems with thermal reactors only were used to develop the thermal reactor factor. Case 2 was used to develop the same factor including also port liners. The results are shown in Table 4-9.

Table 4-9

Effect of a Thermal Reactor and a Thermal Reactor plus Port Liners

System	Factors		
	HC	CO	NOx
Thermal Reactor	0.58	0.81	0.91
Thermal Reactor Plus Port Liners	0.54	0.79	0.73

The thermal reactor effect is considered conservative. There are at least two other recent examples in the literature* that indicate that thermal reactor systems can be quite effective in controlling emissions.

The first paper (SAE paper 760319) shows the dramatic effect of insulating a thermal reactor. Insulation had the same, or greater, effect on HC control than spark retard did. This suggests that thermal insulation can essentially eliminate the need for spark retard, with its attendant fuel economy penalties. The second paper (SAE Paper 760255) presented test results from a 2500 pound vehicle with a 200 cubic inch engine with a thermal reactor. The best fuel economy calibrations obtainable with this vehicle (20.2 mpg urban) yielded emissions of 0.40 HC, 3.0 CO, 1.5 NOx. No catalyst was used.

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* Lean Thermal Reactor Performance - A Screening Study by R.J. Herrin, SAE Paper 760319, presented at the Automotive Engineering Congress and Exposition, Detroit, Michigan, February 1976.

A Spark Ignition, Lean Homogeneous Combustion Engine Emission Control System for a Small Vehicle, by D.J. Pozniak SAE Paper 760225 presented at the Automotive Engineering Congress and Exposition, Detroit, Michigan, February 1976.

Use of a switched out start catalyst was the next technology investigated. Earlier work by EPA yielded the results shown on Table 4-10 as "Earlier Work". More recent data from the GM Status Report and also the literature* are included with the low mileage results of non-switched out start catalysts being used to approximate the effect of a switched-out start catalyst.

It should be noted that the referenced paper used 2 start catalysts that were 3 inches in diameter and only 3/4 of an inch long. Total platinum loading was 0.0035 troy ounces. At a retail price of $150.00 per troy ounce this works out to 53 cents worth of platinum. It is estimated by EPA that the whole system would cost the customer less than 25 dollars.

Table 4-10

Switched-out
Start Catalyst Effect

System	Switched-Out Start Catalyst Factor		
	HC	CO	NOx
Earlier work	0.48	0.36	1.01
Earlier work	0.62	0.45	1.00
Earlier work	0.70	0.66	1.00
Literature	0.60	1.01	0.98
Recent data	0.57	0.46	0.90
Recent data	0.68	0.72	1.20
Average Factor	0.61	0.61	1.02

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* A Guard System to Limit Catalytic Converter Temperature by J.R. Mondt, SAE Paper 760320, presented at the Automotive Engineering Congress and Exposition, Detroit, Michigan, February 1976.

Improved EGR systems were the next technological improvement considered. If a system could be found that controlled NOx without as much of a deleterious effect on HC as even today's best production system, HC benefits could be obtained. Ford possibly tested such a system. Ford's status report includes test results of a "sonic" EGR system from two nominally identical vehicles except for the use of sonic EGR on one vehicle. Both systems had oxidation catalysts, air injection and the same model carburetor. Best effort results were presented by Ford and are shown in Table 4-11.

Table 4-11

Sonic EGR Effect

3 test averages in each case

System	HC	CO	NOx
Backpressure EGR	0.55	3.00	0.77
Sonic EGR	0.21	1.58	0.74
Indicated Factor	0.38	0.53	0.96

It was also reported that the sonic EGR car had better fuel economy than did the other, higher emitting, vehicle.

Other improvements such as improved ignition systems have been reported in the literature*. However, their HC control benefits, shown on engine dynamometer tests, could not be quantified, since 1975 cold-start FTP results were not reported. While it is clear that these improvements along with improvements in fuel atomization* have benefits they remain to be quantified.

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* The Ferroresonant Capacitor Discharge Ignition (FCDI) System: A Multiple Firing CD Ignition with Spark Discharge Sustaining Between Firings by J.R. Asik, et. at., SAE Paper 760266, presented at the Automotive Engineering Congress and Exposition, Detroit, Michigan, February 1976.

The Performance of a Multigap Spark Plug Designed for Automotive Applications, by W.G. Rado, et. al., SAE Paper 760264, presented at the Automotive Engineering Congress and Exposition, Detroit, Michigan, February 1976.

The above discussion shows that much emission control technology remains to be fully integrated and tested to obtain good fuel economy at or below 0.41 HC. In this study estimates of emissions reductions were made for systems that are combinations of the subsystems described above. These combined system have been applied to the highest HC emission value reported earlier as being one that resulted from a good (some might say optimum) fuel economy calibration. The highest value for engine-out HC was 4.1 grams per mile.

System 1	Improved Catalyst, Revised Certification Fuel, Sonic EGR. Engine out 4.1 HC, predicted 50,000 mile tailpipe, 0.34 HC.
System 2	Improved Catalyst, Revised Certification Fuel, Port Liners Switched-Out Start Catalyst. Engine out 4.1 HC, predicted 50,000 mile tailpipe, 0.32 HC

These are only two of the many systems that could be considered to make the good fuel economy engine calibrations achieve HC levels low enough to have high confidence of certifying at a 0.41 HC standard.

Systems like sonic carburetion (which tend to have engine-out emissions much lower than 4.1 HC at best fuel economy) coupled with the other systems discussed above could be configured. Other systems like onboard fuel distillation (factors of 0.48 and 0.54 for HC and CO), and cold storage of HC by means of charcoal (an HC factor of 0.47, 75' FTP basis) could also be considered.

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* Effects of the Degree of Fuel Atomization on Single-Cylinder Engine Performance, by W.R. Matthes, et. al., SAE Paper 760117, presented at the Automotive Engineering Congress and Exposition, Detroit, Michigan, February 1976.

In summary, there are many technological approaches that need to be explored since advanced systems could allow the most stringent emissions standards to be achieved at best fuel economy levels.

4.5 Cost Ranges

The issue of control technology costs has been examined in somewhat more detail than in previous years. Unfortunately, as has been the case in the past, the responses on cost from most manufacturers were not wholly responsive to the request from EPA on cost information. Some manufacturers submitted nothing, most submitted inadequately substantiated information, and only one manufacturer, Mitsubishi, made a real attempt to submit cost information in the desired format.

Some rough estimates of costs based on EPA calculations were made. Much of the information on the costing methodology was taken from a NAS report* and the values shown in Table 4-12 were used to compute the costs.

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* Manufacturability and Costs of Proposed Low-Emissions Automotive Systems, Consultant Report to the Committee on Motor Vehicle Emissions, Commission on Sociotechnical systems, National Research Council, Sept. 1974.

Table 4-12

Costing Information

Item	Value or Range of Numerical Values
Manufactured cost divided by material cost	3
Corporate profit	0 to 10 percent of selling price
Corporate GNA	10 percent of selling price
Tooling	2 percent of selling price
Dealer margin	22 percent of selling price
Ratio of selling price to material cost	4.6 to 5.4 (depends on corporate profit)
Ratio of replacement part cost to material cost	9
Catalyst active material	\$100.00 to \$150.00 per troy ounce
Stainless steel	\$0.50 to \$1.50 per pound
Mild Steel	\$0.06 to \$0.20 per pound
Rubber	\$0.38 per pound
Plastic	\$0.70 to \$0.80 per pound
Charcoal	\$0.10 to \$0.15 per pound
Cast Iron	\$0.05 to \$0.20 per pound

Table 4-13 gives the costs of various components and subsystems that go into making up emission control systems. Costs are given as a range, because there are ranges on the input parameters.

Table 4-13

Ranges of Cost Estimates(1)

Item/Component/Subsystem	Range of Manufacturers Estimates, Dollars	Range of EPA Estimates, Dollars
PCV valve	2 to 3	2 to 3
Evap control	5 to 18	7 to 9
TCS/OSAC	6 to 10	2 to 3
Anti-Dieseling Solenoid	2 to 6	2 to 3
Hardened valve seals	2	2
Air injection system	25 to 140	10 to 20
Air switching system	15 to 30	1 to 4
Reed valve AIR system	15	2 to 6
EGR system (all types)	11 to 53	1 to 2
Pelleted ox cat (each)	35 to 118	96 to 113
Monolithic ox cat (each)	66 to 153	44 to 52
Start catalyst system	75 to 100	41 to 48
Pelleted NOx cat (each)	72 to 150	101 to 118
Monolithic NOx cat (each)	90 to 157	49 to 57
Metallic NOx cat (each)	100	47 to 55
Monolithic 3-way cat (each)	100 to 105	46 to 54
O_2 sensor	5 to 23	5 to 10
New, advanced, fuel metering system	N.R.	10 to 20
Thermal reactor (each)	4 to 86	14 to 26 over std. manifold
Port Liners (per cylinder)	1	.50 to .60
Quick heat manifold	N.R.	8 to 10
SEFE	N.R.	12 to 15
Electric choke	4 to 9	5 to 10
HEI	27 to 116	15 to 25
Improved exhaust system	30 to 40	20 to 30 over old system
Insulated manifold/exhaust pipe	N.R.	15 to 20
Carburetor modifications for altitude compensation and feedback	N.R.	6 to 10
Electronic control unit	105-125	50 to 60

(1) N.R. means not reported

Of more interest, perhaps, are the estimated cost ranges to meet current and future emission standards. These cost ranges are shown in Table 4-14.

Table 4-14

Emission Control System Costs to Meet Various Standards

Emissions Standards HC/CO/NOx (year)	Range of Manufacturer Estimates		Range of EPA Estimates	
	Dollars	Base Year	Dollars	Base Year
3.4/39/3.0 ('74)(1)	N.R.(2)		32 to 95	UC(3)
1.5/15/3.1 ('75-'76 Fed)	136	UC	32 to 125	UC
1.5/15/2.0 ('77 Fed)	0 to 173.20	'75-'76 Fed	32 to 125	UC
0.9/9.0/2.0 ('75-'76 Cal)	33 to 133	'75-'76 Fed		
0.9/9.0/2.0 ('75-'76 Cal)	257	UC	70 to 141	UC
0.41/9.0/1.5 ('77 Cal)	-? to 110.30	'75-'76 Cal		
0.41/9.0/1.5 ('77 Cal)	25 to 205	'75-'76 Fed		
0.41/9.0/1.5 ('77 Cal)	254 to 291	'74	175 to 216	UC
0.41/3.4/2.0	22 to 193	'75-'76 Fed	175 to 216	UC
0.41/3.4/1.0	147 to 360	'75-'76 Fed	175 to 218	UC
0.41/3.4/0.4	35 to 482.86	'75-'76 Fed		
0.41/3.4/0.4	346 to 381	'74	277 to 321	UC

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(1) 1972 FTP; all other emissions on 1975 FTP.

(2) N.R. means not reported.

(3) UC means uncontrolled.

Table 4-14 indicates that the base year for the manufacturer's cost estimates was not always the same.

The reason for the wide range in the EPA cost estimates is that it was considered necessary to treat two different cases to determine the range. One end of the range was determined by estimating the cost for a system to just meet the standards with no consideration whatsoever given to fuel economy. The other end of the range was determined by estimating the cost for a system to meet the standards, but with reasonable or good fuel economy.

Another reason for the range in cost is that there is a range in control system costs for different vehicles, with lighter weight vehicles generally having less expensive emission control systems. EPA estimates reflect the cost for an average car.

It is probably most appropriate to allocate to emission control a dollar figure near to the lower bound cost estimates, and to allocate to fuel economy improvements the difference between the higher and lower cost estimates.

As a final note regarding the cost estimates, it should be noted that the costs for controlling pollutants were not separated for each pollutant. This is because an emission control system controls all of the pollutants to the degree needed. There is currently no accepted method for allocating the costs of an emission control system among individual pollutants.

SECTION 5

THE IMPACTS OF PERMITTING OR NOT PERMITTING CATALYTIC CONVERTER SERVICE ONCE DURING THE 50,000 DURABILITY MILEAGE ACCUMULATION SCHEDULE

5.1 Background

Section 86.077-25(a)(2)(IV) of the emission regulations covering automobiles permits service of the catalytic converter once during the 50,000 mile certification durability test mileage accumulation.

Some foreign manufacturers have used this provision to replace the catalyst (taking the old one off and putting on a new one) once. The change has typically been made at about 25,000 to 30,000 miles.

Most of the vehicles that certified in the past with a catalyst change were intended for sale in California. Late in 1975 the California regulations that apply to catalyst change were revised in a manner that made it unattractive for a manufacturer to use the catalyst change option. Briefly, the California regulations require the manufacturer to provide full warranty coverage (parts, labor, taxes) for the catalyst change, require the installation of a catalyst change reminder service in the car, require the manufacturer to install a doorpost sticker, a window sticker and a notice in the owner's manual advising the car owner of the need for a catalyst change, and require the manufacturer to notify the owner by first class mail when a catalyst change is needed. Also the manufacturer must establish a policy to reimburse the dealers, and must report to the California Air Resources Board the number of catalyst changes made. Finally the dealer has to make a catalyst change on vehicles that need it, the owner permitting.

As a result some of the manufacturers undertook to re-certify without using a catalyst change. Since most of the manufacturers that had used a catalyst change had also been successful in running without a catalyst change, the question arises as to why they did not certify all of their cars without a catalyst change. There could be at least two reasons for this. First, the manufacturers could have been uncertain of this new catalytic technology as applied to their vehicles, and they wanted to make their chances of certifying as high as possible by using the catalyst change option. Second, the manufacturers may have wanted to reduce system first cost by allocating catalyst replacement cost to the maintenance cost of the owner, and also to profit from retail sales of catalysts.

The 1975 and 1976 certification experience clearly indicates that it is not necessary to use a catalyst change to certify at either the 1.5 HC, 15 CO, 3.1 NOx or the 0.9 HC, 9.0 CO, 2.0 NOx standards. However, an important question is the impact of allowing or not allowing a catalyst service on the industry's capability to meet future emission standards.

5.2 Catalyst Service Without a Catalyst Change

Catalyst service could include procedures other than just replacing the catalyst. The use of the service provisions of the regulations to date has been replacement, but there may be other avenues for catalyst service that are not replacement with a new catalyst.

Catalyst regeneration is an approach that could potentially be used. Some catalysts used in the oil industry are routinely regenerated in situ. However in many cases this involves treatment with a reducing gas like CO at high temperature, possibly with the addition of special additives. This approach may be too sophisticated for the average dealer or garage due to equipment needs. Also, process catalysts generally see a more controlled history than automobile catalysts do. One of the reasons regeneration works is that poisons are removed from the catalyst. Therefore, if poisons could be removed from automobile catalysts while they remain on the vehicle this type of catalyst service may be attractive. Two approaches could be tried, one in which an additive was put into the fuel/air mixture, in a manner similar to today's carburetor cleaners. Another approach, mentioned by GM, is to pour something in the exhaust pipe that would remove the catalyst poisons, tilt the car and have the solvent go into the catalyst, and then remove the catalyst poison-laden solvent.

Another technique would require that the catalyst be removed, reconditioned and then replaced. Catalyst regeneration work has been reported* using acetic acid and ammonium acetate. Laboratory results showed good post-regeneration efficiency but more extensive regeneration (two 3-hour treatments at 195^{o}F with ultrasonic agitation, compared to washing at room temperature for one-half hour) was required to return the rate of activity loss after regeneration to what the original catalyst demonstrated. If facilities and equipment were available, a new service industry could be created. For example, an industry exists today to rebuild engines, carburetors, electrical components, etc. It is not impossible to conceive of a catalyst reconditioning industry. The customer would take his car (or catalyst) in and get a credit for the old catalyst, and get a "rebuilt" put in. This assumes that his old catalyst could not be regenerated in a short time.

The major problem with the regeneration approach, either on the car or as an off-the-car reconditioning, is that the vehicle results with catalysts that have been regenerated have shown poor post-regeneration efficiency with accumulated mileage. The newly-regenerated catalyst can have good, near fresh, efficiency, but in the vehicle tests run to date the efficiency has been quickly lost, more quickly than the original catalyst lost its efficiency before the regeneration. The reasons are not well understood.

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* "Rejuvenation of Lead-Poisoned Noble Metal Catalyst" by Walter C. Rothschild, SAE Paper 760321, presented at the Automotive Engineering Congress and Exposition, Detroit, Michigan, February 23-27, 1976.

One catalyst deterioration mechanism that does not appear to be amenable to regeneration is thermal degradation. This could put an upper limit to the effectiveness of this approach.

Thus that catalyst regeneration is potentially a viable concept, it cannot be relied on now as an equally effective alternative to replacement of a catalyst with a new one.

5.3 Catalyst Service via Catalyst Replacement

Catalyst replacement is the most effective service technique at this time. Some manufacturers are considering this option, at least as a backup, for the 1977 California standards of 0.41 HC, 9.0 CO, 1.5 NOx.

The other consideration related to the catalyst change and future standards was made by EPA in the Technical Appendix to the Administrator's Decisions on the Suspension of the 1977 Auto Exhaust Emission Standards. The standards under consideration were 0.41 HC, 3.4 CO, 2.0 NOx. The impact of the use of a catalyst change at these levels is shown in Table 5-1.

Table 5-1

Effect of Using a Catalyst Change on Certification Capability - as of March, 1975

(Standards: 0.41 HC, 3.4 CO, 2.0 NOx)

Percent of the Market Projected to Certify Successfully

Without Catalyst Change	With Catalyst Change
0	100% of domestic production

For this report, the same case was re-examined. The analysis has been modified somewhat. When the catalyst-change portion of the EPA Monte Carlo analysis was originally developed a catalyst-change was simulated by considering the new catalyst emissions as an after-maintenance test point at the catalyst-change point, and replacing the data beyond the catalyst-change point by the data before the catalyst-change. Thus, if the catalyst change was simulated at 30,000 miles, the actual 30,000 mile point was used as the before maintenance point, and the zero-mile data point was used as the after maintenance point. The new 35,000 mile point was the 5,000 mile point, and so on. Because no actual catalyst change data existed then, an adjustment factor of 1.1 was put on HC and CO emissions to simulate engine-out deterioration. This was conservative, since it built-in more deterioration.

Now there are actual certification catalyst change data to study. The actual catalyst change data was compared to the results predicted by the methodology. For the vehicles studied the adjustment factor was then varied until the difference between the average actual DF and the average DF projected by the methodology was driven to zero. The results are shown on Table 5-2.

Table 5-2
Adjustment Factors to Simulate a Catalyst Change

Factors to Make Difference in Average Projected and Average Actual Values Vanish

	Old Factors	DF	50K extrapolated emissions	New Factors
HC	1.1	1.07	1.00	1.1
CO	1.1	0.95	0.96	1.0
NOx(A)*	1.0	<1.00	<1.00	1.0
NOx(B)*	-	-	-	1.1

*HC and CO are assumed to be catalytically controlled. For NOx the two cars are (A) NOx is not catalytically controlled, (B) NOx is catalytically controlled.

It can be seen from Table 5-2 that the new adjustment factors are still somewhat conservative.

Also, new Monte Carlo tables were generated for the future standards of interest, including the standards shown in Table 5-3.

Table 5-3

Standards Examined

HC	CO	NOx
0.41	3.4	2.0
0.41	9.0	1.5
0.41	3.4	1.0*
0.41	3.4	0.4

*Two cases were considered, one in which NOx is not catalytically controlled, the other in which NOx is catalytically controlled. The variances in car-to-car, test-to-test, and DF were the same as for HC for the catalytic control of NOx use.

Table 5-4

Effect of a Catalyst Change at Different Standards

Confidence Level	Catalyst Change(cc) or no Catalyst Change (No cc)	No. of Vehicles Studied	% that Passed .41 HC, 3.4 CO, 0.4 NOx	No. of Vehicles Studied	% that Passed .41 HC, 3.4 CO 1.0 NOx	No. of Vehicles Studied	% that Passed .41 HC, 3.4 CO 2.0 NOx	No. of Vehicles Studied	% that Passed .41 HC, 9.0 CO 1.5 NOx
(1)	No cc	2	0	6	0	80	18	8	0
(1)	cc	2	0	6	33	85	56	10	0
(2)	No cc	2	100	6	33	80	44	8	13
(2)	cc	2	100	6	50	85	74	10	2
(1)	No cc*	-	-	-	-	80	41	8	0
(1)	cc*	-	-	-	-	85	74	10	0
(2)	No cc*	-	-	-	-	80	74	8	25
(2)	cc*	-	-	-	-	85	92	10	30

* Case includes factors

(1) Had greater than 80 percent probability of successfully certifying

(2) Did not line cross, i.e. "met" the standards, but the probability of certifying is less than 80 percent.

Table 5-4 is conservative because not many vehicles were available with full systems targeted toward 0.4 or 1.0 NOx.

Also, only partial data were available on systems targeted toward the 1977 California standards of 0.41 HC, 9.0 CO, 1.5 NOx. Also some vehicles had to be considered at standards other than those for which they were targeted, i.e., 0.4 NOx cars at 1.0 NOx.

5.4 Fuel Economy and Cost Impacts of a Catalyst Change

The range of fuel economy effect due to a catalyst change is shown in Table 5-5. Most of the benefit is due to lower DF, and only a slight benefit is due to reduced DF variability.

The cost of a catalyst change is one important part of the study of the catalyst change. The subject of catalyst change costs is discussed below.

Table 5-6 lists the catalyst change costs provided by the manufacturers.

Table 5-5
Effect of a Catalyst Change
on Fuel Economy

Emission Standards HC/CO/NOx	Range of Fuel Economy Effect, Percent
0.41/3.4/2.0	+4 to +8
0.41/9.0/1.5	+1 to +2
0.41/3.4/1.0*	+3 to +6

* NOx is catalytically controlled

Table 5-6

Catalyst Change Costs
(per catalyst)

Catalyst Type	Range of Manufacturer Estimates	Average Manufacturer Estimates
Pelleted oxidation	(A) $60.00 to $70.00	
	(B) $69.95 to $173.79	
	(C) $30.90 to $49.80	
		$53.62 to $97.86
Monolithic oxidation	(A) $169.60	
	(B) $395.00 to over $1000.00	
	(C) $97.00	
		$220.53 to 455.53
Pelleted reduction	(A) $70.30 to $128.60	
		$70.30 to $128.60
Nonpelleted reduction	(A) $107.20	
	(B) $285.00	
	(C) $106.60 to $190.10	
		$166.23 to $194.10
3-Way	(A) $162.00	
	(B) $100.00	
	(C) $150.00	$137.34
Start	(A) $107.20	$107.20
O_2 Sensor	(A) $9.20 to $19.20	
	(B) $30.00	
	(C) $20.00	
		$19.74 to $23.08

As can be seen from the above table, the cost estimates for a catalyst change vary widely. This could be because there is a range on all of the costs that go into making up the total cost, i.e. materials, OEM versus replacement part costing, labor, etc.

EPA has developed catalyst change cost estimates based on Table 5-7. The amounts are listed as ranges to allow for system differences and the uncertainty of the estimate. Note that the catalytically active material costs are given as platinum equivalents, except for the metallic NOx catalyst. The range on platinum costs is from the quoted price of $150.00 per troy ounce down to $100.00 per troy ounce. The lower bound for the range is given because the large volume customer typically gets a discount and platinum should be no different.

The cost estimates are shown in Table 5-8.

Table 5-7

Ranges of Items that Affect Catalyst Change Costs

Item	Range
Catalyst loading	0.02 to 0.20 troy ounces per catalyst
Active material cost-noble metal	$100.00 to $150.00 per troy ounce
-non-noble metal	$0.50 to $1.50 per pound
Stainless steel	$0.50 to $1.50 per pound
Converter housing weight	3 to 20 pounds (pelleted) 2 to 5 pounds (monolithic)
Substrate cost	$0.25 to $2.00 per pound
Substrate weight	4 to 6.5 pounds (pelleted) 1 to 4 pounds (monolithic)
Metallic NOx catalyst weight	3 to 6 pounds
Labor cost	$11.00 to $17.50 per hour
Catalyst replacement labor time	0.5 to 1.5 hours
Ratio of material cost to OEM cost	4.6 - 5.4*
Ratio of material cost to replacement cost	9 to 12

* Manufacturability and Costs of Proposed Low-Emissions Automotive Engine Systems, National Research Council, September 1974 and Report by the Committee on Motor Vehicle Emissions, National Academy of Sciences, February 1973.

Table 5-8
Catalyst Change Costs (per catalyst)

Catalyst Type		Cost Estimate	Range of
	Lowest Estimate	Highest Estimate	Report Estimate
Pelleted oxidation	(A) $15.70	$258.40	$38-44
	(B) $24.50	$413.20	$68
Monolithic oxidation	(A) $16.85	$271.90	$52-50
	(B) $26.75	$435.70	$95
Pelleted Reduction	(A) $15.70	$258.40	$43-49
	(B) $24.50	$413.20	$77
Monolithic Reduction	(A) $16.85	$271.90	$57-66
	(B) $26.75	$435.70	$104
Metallic Reduction	(A) $18.00	$115.30	$53-63
	(B) $29.00	$174.70	$100
Monolithic 3-Way	(A) $16.85	$271.90	$55-63
	(B) $26.75	$435.70	$98
Monolithic Start	(A) $16.85	$215.20	$31-38
	(B) $26.75	$341.20	$48

(A) Cost for the replacement catalyst the same as OEM part, as if the replacement price were included in the vehicle's first cost.

(B) Cost for the replacement catalyst based on the estimated cost, as if the catalyst cost was like other replacement parts.

Table 5-8 indicates that a major effect on the cost of a catalyst change is whether or not the price of the catalyst is considered as an OEM part or as a replacement (retail) part. Both estimates are presented, since the cost of the catalyst change would be much closer to the lower figure if actions were taken that would tend to include the cost in the first purchase cost of the automobile.

5.5 Summary

Use of a catalyst change is not necessary at emission levels down to 0.9 HC, 9.0 CO, 2.0 NOx. To meet Federal standards of 0.41 HC, 3.4 to 9 CO, and NOx standards of 1.5 NOx to 2.0 NOx would require a catalyst change if the technology used is the same as that for 1977 model year. HC is the problem. At 0.41 HC, 3.4 to 9 CO, and a NOx standard of 1.0 NOx, improvements in technology are also needed before a catalyst change becomes unnecessary. The same is even more true for the 0.41 HC, 3.4 CO, 0.4 NOx case. This is summarized in Table 5-9.

Table 5-9 indicates that not allowing a catalyst change tends to stretch out the time at which future stringent emission standards can be met and that more emission control technology improvements will be needed to meet lower standards.

It was estimated in this study that the per catalyst cost of a catalyst change is about \$35.00, if the cost is included in the purchase price of the automobile, and about \$85.00 if the replacement catalyst is treated as a conventional replacement part. The cost differential is attributable to differences between warranty parts and labor cost schedules versus retail trade levels.

Table 5-9

Impact of a Catalyst Change on the Ability to Meet Various Standards

Federal Emission Standard HC/CO/NOx	Is a Catalyst Change Required to meet the Federal Standards?	Technology Used	Earliest Model Applicable
1.5/15.0/3.1	No	1975/1976 Production	1975
0.9/9.0/2.0	No	1975/1976 Production	1975
0.41/9.0/1.5	Yes(1)	1977(2) Production	1978(Fed)
0.41/3.4/2.0	Yes	1977 Production	1978(Fed)
0.41/3.4/2.0	No	1977 Production + improvements(3)	1979
0.41/3.4/1.0	Yes	3-Way+Ox.Cat (carbureted)(4)	1980-83(Fed)
0.41/3.4/1.0	No	3-way(Carbureted improvements(5)	1981-84
0.41/3.4/0.4	Yes	Dual Cat.(6) or 3-way	1981-1985
0.41/3.4/0.4	No	Dual Cat.(7) or 3-way	1981-1985

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(1) Based on preliminary 1977 certification results, (2) The technology being run for certification for 1977 California production, (3) These improvements have already been demonstrated, (4) This technology is in development durability testing now. (5) Known improvements, yet to be durability tested. (6) Includes 3-way + ox. cat. Little testing is being done. (7) Requires catalyst technology improvements not yet durability tested.

The above discussion presents some information that may bear on the issue of whether catalyst change should be permitted. However, it should be pointed out that the major question that impacts on the catalyst change issue is: Will the catalysts be changed in the field? The answer to this question is not a technical one. However, given current maintenance practices and the problems encountered in implementing inspection and maintenance, it is concluded that the percent of catalysts that will get changed in the field is likely to be substantially below 100 percent.

SECTION 6

INDUSTRY STATUS

6.1 Industry Status - 1977 Model Year

As far as the meeting 1977 Federal Standards are concerned, there appears to be no major problems at this point in time. Most manufacturers will use systems much like the 1976 Federal systems, with more widespread use of better EGR systems. Although some manufacturers will use improved catalysts, the revised certification fuel probably makes this less than absolutely necessary. Because the 1977 Federal standard for NOx is different (2.0 NOx in 1977 versus 3.1 NOx in 1976) recertification of some models is necessary. However, most manufacturers are recertifying most models possibly to take advantage of the revised certification fuel. The lower DF's with the revised fuel should have benefits which can be taken in improved fuel economy.

From a technological standpoint, the 1977 California systems are of the most interest. Some manufacturers may use systems which could be forerunners of the improved technology needed to meet future standards that may be mandated nationwide. However, California has adopted easier to meet ground rules for demonstrating compliance with emission standards. This means that, while meeting 0.41 HC may be feasible in California the capability to meet 0.41 HC on a Federal basis has not been proven for all cars by the results of the 1977 California cars.

There will be some use of start catalyst systems (AMC, Chrysler, possibly GM), and some use of 3-way catalysts (Volvo, Saab). There may also be used, by at least one manufacturer, systems that use reduction and oxidation catalysts (three way plus oxidation catalyst and dual catalyst systems).

These systems are considered to be a promising first step in the development of future systems, but only a first step. The lead time has been too short to develop fully optimized systems. In addition, the California market may be too small to justify the development of the better systems that could have been introduced for California.

Finally, the gap between the Federal and the California standards is quite large for 1977. The manufacturers may not be planning full effort systems for California for 1977 if standards of similar stringency will not be required on a Federal basis for many years.

6.2 Industry Status - Post - 1977 Model Year

Although development work is underway on a variety of projects at most manufacturers, the definite impression is that most of the industry is waiting to see what happens to the Clean Air Act amendments now under consideration by Congress. The manufacturers' desire not to expend limited resources on what they do not have to do, coupled with the drain on technical manpower for high priority fuel economy programs, has slowed down development programs, especially those targeted for low NOx levels.

For the post-1977 timeframe, there is much work going on in the development of subsystems that could become a part of future emission control systems. Some of these areas were discussed in Section 2 under significant development trends. The development of some other subsystems may be considered as fuel economy development by a few manufacturers, and may not have been reported to EPA.

Assembling full effort systems, optimizing them, and operating the extensive development durability fleets that are required to fully investigate the capability to meet future standards is a lengthy, costly effort. This effort significantly lags the development of the subsystems. Some estimates of how long this process of putting together the systems and running the required development and certification vehicle fleets has been made. These estimates are shown on Figures 6-1, and 6-2.

Figure 6-1 is for meeting 0.41 HC, 3.4 CO and 0.4 NOx. The emission control system to be used was assumed to be a dual catalyst system using a metallic NOx catalyst, for the purpose of estimating lead time. Two pre-certification development fleets are needed to fully test, evaluate and pick the best system. Doing the development testing and preparing the production facilities will take the time indicated on the upper chart, which results in model year 1980 as the earliest date at which compliance with the 0.41 HC, 3.4 CO, 0.4 NOx standards can be estimated. This scenario is based on expanded effort compared to the level of effort seen today.

Figure 6-2 is a chart for an effort that would result in some fraction (say 10%) of a manufacturer's production meeting standards of 0.41 HC, 3.4 CO, 1.0 NOx. This estimate is a higher risk one for the manufacturers since only one development fleet is projected. The emission control system was assumed to be a 3-way catalyst with a feedback carburetor. The lead time for a fuel injected system would be longer. With this high effort, high risk schedule meeting 0.41 HC, 3.4 CO, 1.0 NOx in 1979 may be possible for a limited number of vehicles, less than 100% of production.

It must be emphasized that the estimates made in Figures 6-1 and 6-2 assume an expanded level of effort over and above what exists today, and that such expanded effort must start now. If these assumptions are not met, meeting the standards at the dates indicated may not be possible. EPA evaluation of the current emphasis given by manufacturers on emissions control development is that existing programs would have to be substantially accelerated to meet the schedules in both figures.

Figure 6-1
Lead Time Schedule for Meeting 0.41 HC, 3.4 CO, 0.4 NOx

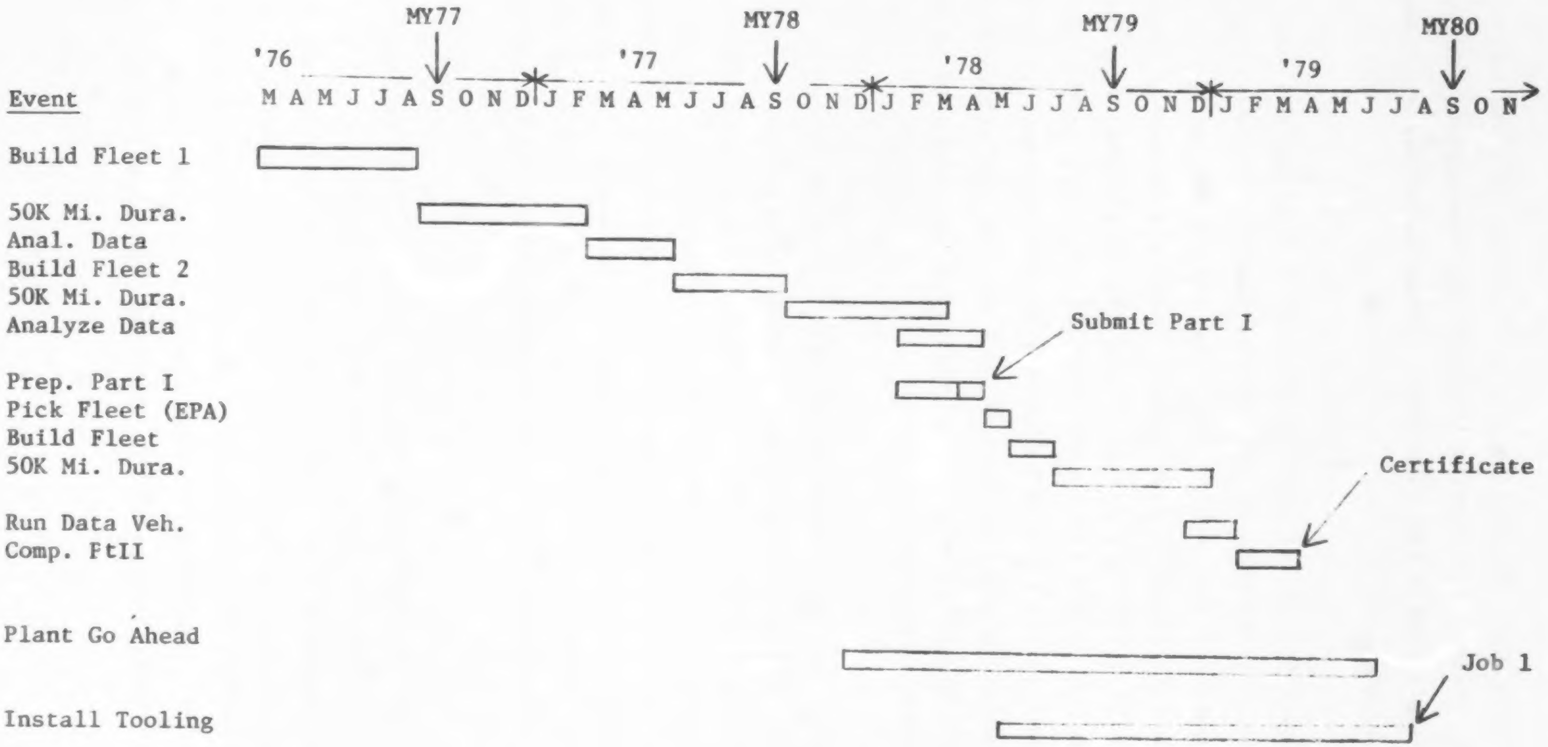
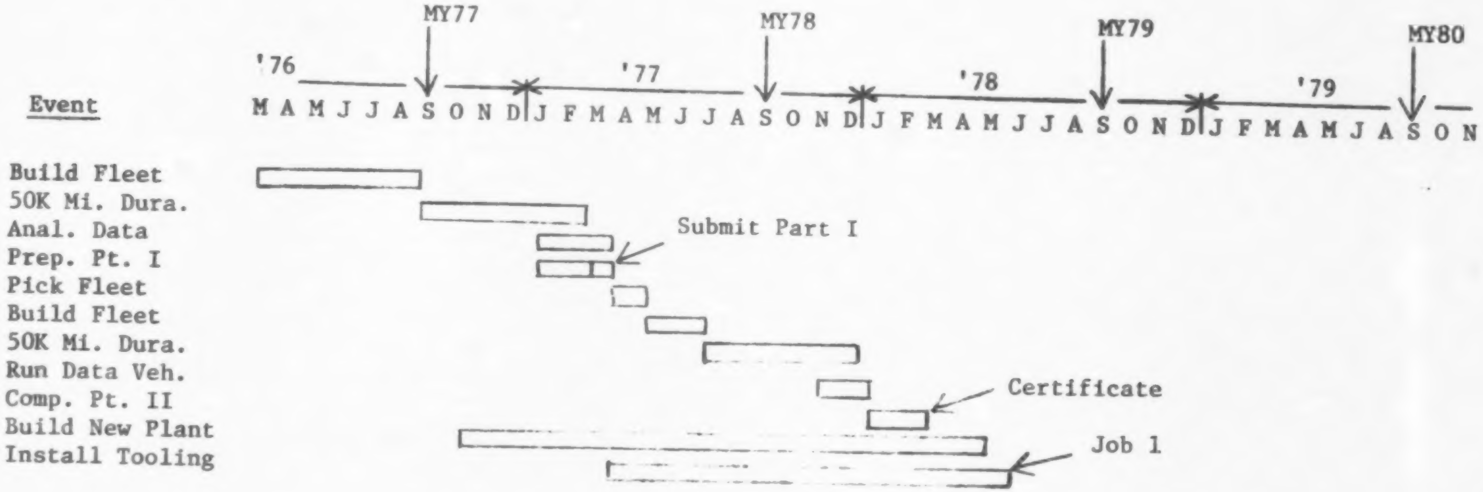


Figure 6-2
Lead Time Schedule for Meeting 0.41 HC, 3.4 CO, 1.0 NOx
on a Less than Full Production Basis



SECTION 7

INDIVIDUAL MANUFACTURER REVIEWS

7.1 Domestic Manufacturers

7.1.1 American Motors

7.1.1.1 Systems to be Used

Systems to be Used - 1977 Model Year

The 1977 AMC systems will be a refinement of the 1976 systems plus the additional application of catalytic converters. The 49 state vehicles will include a newer combustion chamber shape, backpressure regulated EGR, transmission controlled spark on vehicles sold at altitude, EFE, and a pellet type oxidation catalyst. A summary of the 49 engine families can be found in Table AMC-1. For the California vehicles refer to Table AMC-2. The principal difference between these vehicles will be the use of a start catalyst. Other differences for 1977 will be the lack of availability of some engine families at altitude and the 4 cylinder engine unavailability in California.

AMC will continue to use the pelleted catalyst supplied by AC Spark Plug division of General Motors. Their start catalyst will be Engelhard monoliths, two of which are used for eight cylinder engines and one of which is used for a six cylinder engine.

AMC projects that there will be a minimal fuel economy penalty to a slight fuel economy gain for the 1977 model year versus the 1976 model year. AMC speculates that only half of their present models will be able to receive California certification since their precertification fleets have not provided an acceptable emission control margin for compliance.

Table AMC-1

AMERICAN MOTORS EMISSION CONTROL SYSTEMS

	1977 MODEL YEAR LIGHT DUTY VEHICLES (49 STATES)						
ENGINE & CARB. VENTURI	4 Cyl. 2V (Z)	6 Cyl. 1V (X)	6 Cyl. 1V	6 Cyl. 1V (Z)	6 Cyl. 2V (Z)	8 Cyl. 2V (Z)	8 Cyl. 2V
MODEL + TRANSMISSION	40 A & M	(01-60-40) (A)	(01-60-40) (M)	10 (A)	(40-60-01) (A)	01-10-80	10-80
GENERIC SYSTEM	EGR + CAT	EGR + AIR	EGR+AIR+CAT	EGR+AIR+CAT	EGR + AIR	EGR+AIR+CAT	EGR+AIR+CAT
ENGINE TYPE & DISPLACEMENT	S.I. Recip. 4 Stroke 121 C.I.D.	S.I. Recip. 4 Stroke 232/258 C.I.D.	S.I. Recip. 4 Stroke 232/258 C.I.D.	S.I. Recip. 4 Stroke 258 C.I.D.	S. I. Recip. 4 Stroke 258 C.I.D.	S.I. Recip. 4 Stroke 304 C.I.D.	S.I. Recip. 4 Stroke 360 C.I.D.
COMBUSTION CHAMBER TYPE	Flat-low quench	New	New	New	New	'76 C/O	'76 C/O
INTAKE SYSTEM	Water heated Aluminum-OHC	'76 EFE C/O	'76 EFE C/O	'76 EFE C/O	New + EFE	'76 C/O	'76 C/O
EXHAUST PORT & MATERIAL	Conv. Cast Iron	'76 C/O	'76 C/O	'76 C/O	'76 C/O	'76 C/O	'76 C/O
IGNITION SYSTEM	Breaker Point	Breakerless	Breakerless	Breakerless	Breakerless	Breakerless	Breakerless
EGR	B/P Reg. EGR	V/P Reg. EGR	B/P Reg. EGR	B/P Reg. EGR	B/P Reg. EGR	B/P. Reg. EGR	B/P Reg. EGR
AIR INJECTION	None	19 C.I.D. Pump	19 C.I.D. Pump	'76 C/O	19 C.I.D. Pump	'76 C/O	'76 C/O
THERMAL REACTOR	None	None	None	None	None	None	None
CATALYST	One Oxidizing	None	One Oxidizing	One Oxidizing	None	One Oxidizing	One Oxidizing
TCS	None	Yes	None	Yes	None	None	None
FUEL	Lead Free	Lead Free	Lead Free	Lead Free	Lead Free	Lead Free	Lead Free

SUFFIX LEGEND:

(M)	Manual Transmission
(A)	Automatic Transmission
(C/O)	Carryover
(X)	Catalytic Converter added for Alt. Reg.
(Z)	Not Available at Altitude

MODEL DESIGNATION LEGEND:

01	Hornet
40	Gremlin
60	Pacer
10	Matador Coupe
80	Matador 4-Door and Wagon

Table AMC-2

AMERICAN MOTORS EMISSION CONTROL SYSTEMS

	1977 MODEL YEAR LIGHT DUTY VEHICLES (CALIFORNIA)			
ENGINE & CARB. VENTURI	6 Cyl. 1V	6 Cyl. 2 V	8 Cyl. 2V	8 Cyl. 2V
MODEL	40-01-60	40-01-60	01-40-10-80	10-80
GENERIC SYSTEM	EGR + AIR + CAT	EGR + AIR + CAT	EGR + AIR + CAT	EGR + AIR + CAT
ENGINE TYPE & DISPLACEMENT	S.I. Recip. 4 Stroke 232/258 C.I.D.	S. I. Recip. 4 Stroke 258 C.I.D.	S. I. Recip. 4 Stroke 304 C.I.D.	S. I. Recip. 4 Stroke 360 C.I.D.
COMBUSTION CHAMBER TYPE	New	New	'76 C/O	'76 C/O
INTAKE SYSTEM	'76 EFE	New	'76 C/O	'76 C/O
EXHAUST PORT & MATERIAL	'76 C/O	'76 C/O	'76 C/O	'76 C/O
IGNITION SYSTEM	Breakerless with Recalibration	Breakerless with Recalibration	Breakerless with Recalibration	Breakerless with Recalibration
EGR	'76 Calif. C/O with Recalibration	'76 Calif. C/O with Recalibration	'76 Calif. C/O with Recalibration	'76 Calif. C/O with Recalibration
AIR INJECTION	'76 C/O	'76 C/O	'76 C/O	'76 C/O
THERMAL REACTOR	None	None	None	None
CATALYST	Two Oxidizing	Two Oxidizing	Four Oxidizing	Four Oxidizing
TCS	Yes	Yes	Yes	Yes
FUEL	Lead Free	Lead Free	Lead Free	Lead Free

MODEL DESIGNATION LEGEND:

01	Hornet	10	Matador Coupe
40	Gremlin	80	Matador 4-Door and Wagon
60	Pacer		

The AMC projected first cost of the 1977 California system over the 1976 California system, dictated by the start catalyst, will be an increase of 56.00 dollars for the 6 cylinder engine families and 110.00 dollars for the V-8 families. These costs are somewhat higher than other manufacturer cost estimates. No projected catalyst change data was provided due to lack of system definition.

Systems to be Used - Post 1977 Model Year

.41 HC, 3.4 CO, 1.0 NOx*

AMC stated that these standards have never been actively considered by their corporation. They did provide the information found in Table AMC-3 which summarizes AMC's speculation regarding these levels. They did not provide any fuel economy or cost data for these levels. Notice the inconsistency for the Diesel, the minimum NOx potential is said to be 2.0 but "All" vehicles are apparently under consideration with the Diesel as a 1.0 NOx candidate.

0.4 HC, 3.4 CO, 0.4 NOx

AMC continues to believe that the Gould reducing converter is the only available system having a remote possibility of achieving 0.4 NOx. They have indicated that they have increased their developmental efforts to achieve the desired emissions levels. The systems considered by AMC for 1978 model year are shown in Table AMC-4. These systems consist of a dual catalyst system with backpressure EGR, switching AIR, TCS and the improved '77 combustion chamber. Four and six cylinders models will use one reduction catalyst while eight cylinder models will use two.

The low mileage fuel economies are shown in Table AMC-5.

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*Hypothetical

Table AMC-3

1.0 vs. 0.4 NOx SYSTEM COMPARISONS

SYSTEM	MIN. NOx POTENTIAL *	SYSTEM CONSIDERED FOR 0.4 NOx	SYSTEM CONSIDERED FOR 1.0 NOx	REASONS FOR 1.0 NOx CONSIDERATION AND OTHER IMPACTS
1. EGR and Spark Retard	1.5 for 6 & V8 1.0 for 4 cyl.	No	4 cyl. engine	Production units exist with no packaging problems. Driveability uncertain. Fuel economy loss. Low cost and maintenance requirements. Restricted to light weight vehicles only at standard listed.
2. Three Way Catalyst + EGR	1.0 for 6 & V8 Slightly lower for 4-cylinder	No	All	Technology exists but is limited, unknown durability and complex fuel/air control required. Limited fuel economy potential. No in-house system test data available at this date.
3. Red. Conv. (Gould)	1.5 for 6 & V8 1.0 for 4 cyl.	No	4 cyl. engine	Complex packaging, limited development, unknown durability, reduced fuel economy.
4. Red. Conv. + EGR	.6 for 6 & V8 May be lower for 4-cylinder	No	All	Same as (3)
5. Diesel	2.0	No	All	Improved fuel economy and potential particulate, odor, noise and sulfate problems. High initial investment. Increased powerplant weight.
6. Stratified Charge 3-Valve	2.0 for 4, 6, V8 cylinder engines	No	No	Fuel economy potential uncertain and no 4-cylinder engine experience to date.
7. Rotary + EGR	1.0	No	No	Fuel economy considered inferior.

* This does not imply or represent knowledge of the required certification margin or Selective Enforcement Audit margin needed for a production feasible system.

Table AMC-4

AMERICAN MOTORS EMISSION CONTROL SYSTEMS

1978 MODEL YEAR LIGHT DUTY VEHICLES (50 STATES)				
ENGINE & CARB. VENTURI	4 Cyl. 2V	6 Cyl. 1V	6 Cyl. 2V	8 Cyl. 2V
MODEL	40-01	01-40-60-10	01-40-60-10	10-80
GENERIC SYSTEM	EGR + AIR + CAT	EGR + AIR + CAT	EGR + AIR + CAT	EGR + AIR + CAT
ENGINE TYPE & DISPLACEMENT	'77 C/O	'77 C/O	'77 C/O	'77 C/O
COMBUSTION CHAMBER TYPE	'77 C/O	'77 C/O	'77 C/O	'77 C/O
INTAKE SYSTEM	Modified Intake Manifold	Modified Intake Manifold	Modified Intake Manifold	'77 C/O
EXHAUST PORT.	'77 C/O	'77 C/O	'77 C/O	'77 C/O
IGNITION SYSTEM	'77 C/O	'77 C/O	'77 C/O	'77 C/O
EGR	'77 C/O With Recalibration	'77 C/O With Recalibration	'77 C/O With Recalibration	'77 C/O With Recalibration
AIR INJECTION	Programmed to Switch from Oxid. to Red.	Programmed to Switch from Oxid. to Red.	Programmed to Switch from Oxid. to Red.	Programmed to Switch from Oxid. to Red.
THERMAL REACTOR	None	None	None	None
CATALYST	One Oxidizing + One Reducing *	One Oxidizing + One Reducing *	One Oxidizing + One Reducing *	Two Oxidizing + Two Reducing *
TCS	Yes	Yes	Yes	Yes
FUEL	Lead Free	Lead Free	Lead Free	Lead Free

* Reducing converter will utilize a small oxidizer ahead of it, which may be packaged in the same canister with the reducing element.

MODEL DESIGNATION LEGEND:

01	Hornet
40	Gremlin
60	Pacer
10	Matador Coupe
80	Matador 4-Door and Wagon

Table AMC-5
Fuel Economy Comparisons of AMC Models

				75/76 Fed Dur Veh			75/76 Cal Dur Veh			Prototype				
Eng	Trans	IW	VIN	5000 mi MPG	Range 4K-50K	VIN	5000 mi MPG	Range 5K-50K	VIN	Target Std	5000 mi MPG	% Change From Fed	% Change From Cal	Range
232	A3	3500	-------	----	---------	D40-19K	14.5	13.8-17.0	D44-9L*	1	14.8	-----	+3	13.2-15.2
258	A3	4000	D51-13K	14.4	14.3-15.8	-------	----	---------	SOHIO1ø	4	17.4	+20.8	--	14.9-17.4
258	A3	4000	D51-13K	14.4	14.3-15.8	-------	----	---------	SOHIO2ø	4	16.8	+11.7	--	14.7-17.4
258	A3	4000	D51-13K	14.4	14.3-15.8	-------	----	---------	SOHIO3**	1	12.1	-15.7	--	11.1-15.0
258	A3	4000	D51-13K	14.4	14.3-15.8	-------	----	---------	SOHIO4**	1	15.9	+10.1	--	---------

Note: Target Standard Code:
1.5/15/2.0 = 6
0.9/9.0/2.0 = 5
.41/9.0/1.5 = 4
.41/3.4/2.0 = 3
.41/3.4/1.0 = 2
.41/3.4/0.4 = 1

* At 6200 miles .54 HC, 5.94 CO, 4.0 NOx Gould catalyst system + AP

ø Three-way catalyst + AP + OC @ 8000 miles

** Gould system + AP + OC @ 8000 miles

Other Systems

AMC indicated that all development and design work was stopped on the rotary engine early in 1975. With the exception of the following test results, AMC had little comment on their rotary engine program.

Table AMC-6
RC2-60 Rotary Engine

	Emissions (grams/mile)			Fuel Econ. Urb.
System	HC	CO	NOx	MPG
Lean Carb + 260 in^3 Ox. Cat.	1.66	7.26	1.85	13.5
Start Cat + Ox. Cat.	.80	2.72	1.78	15.3

7.1.1.2 Durability Testing Programs

Durability Testing Program - 1977 Model Year

AMC conducted durability testing on six vehicles at the 1977 49-state and California emission levels. The objective of the two 49-state vehicles was to assess the effects of air injection while accumulating durability and fuel economy data on the project 1977 system. The four California vehicles were used to assess the durability of the start catalyst system at two HC and CO levels. Two vehicles have finished 50,000 miles while the remainder have completed 30,000 miles plus.

Durability Testing Program - Post-1977 Model Year

AMC continues to work on the Gould reducing converter system. Over the last ten months, AMC has tested to 23,000 miles a Gould system on a 6 cylinder 232 CID, 3500 lb IW automatic transmission vehicle (D44-9L). The vehicle was terminated due to a combination of exhaust system material failures and engine malfunctions. Subsequently, two additional vehicles were constructed to not only evaluate the Gould system but also the difference in light-off time of a monolith (D50-4L(K)) versus pelleted oxidation catalyst (D50-2L(K)). The vehicle with the pelleted catalyst is now undergoing tests while the other vehicle is being tested by EPA for unregulated emissions.

AMC also ran a SOHIO fleet of four vehicles to provide durability information on systems that were targeted near the 1978 levels. The engine calibrations for these vehicle utilized the same calibration specifications with the only system differences occurring in either the utilization of a Gould reducing converter or an Engelhard three way preconverter ahead of the AC Model 160 pelletized underfloor oxidizing converter. Air switching from the oxidizing converter inlet to the cylinder head exhaust manifold parts was used on all vehicle for oxidation of HC and CO control purposes during a cold start. After the coolant reached 115°F the air would be switched to the inlet of the underfloor oxidizing converter. The test results are tabulated in Table AMC-7. Extensive maintenance was performed during these tests.

7.1.1.3 Progress and Problem Areas

Progress and Problem Areas - 1977 Model Year

AMC anticipates that both a recalibration of EGR and use of TCS will allow some of their automatic transmission six cylinder models to meet the 1977 Federal standards and a recalibration only of EGR for the remaining six and eight cylinder models will accomplish certification. Further they anticipate no problems with certification of their new four cylinder engine for 49 states. AMC is pessimistic on their manual transmission 49-state vehicles for meeting the 2.0 NOx levels with good HC control. The data presented to EPA indicates that AMC should be able to certify their 49-states vehicles and retain a competitive level of fuel economy. The single vehicle data presented for the manual transmission vehicles indicates that AMC has tried to improve fuel economy and driveability by reducing EGR ratio resulting in their low confidence

Table AMC-7

Gould Reduction Catalyst and TWC Results

Vehicle ID	System	Engine	Trans.	IW	Mileage	Emission Results HC	Emission Results CO	Emission Results NOx	Fuel Economy MPG	Remarks
D44-9L*	Gould			3500	0	.43	6.4	.500	14.4	Zero mile GEM 68
					3,550	.51	3.89	.453	15.1	
					14,380	.83	18.6	.366	13.1	Tighten AP belt
					------	.54	3.0	.467	13.2	New Ox Cat
					20,000	.69	7.7	.863	15.2	
D50-4L*	Gould			3500	0	.25	1.4	.71	15.4	Average of 2 tests
					------	.33	3.1	.51	14.5	No spark Adv. till 160°F coolant
D50-2L*	Gould			3500	0	.33	4.4	1.59	13.7	Baseline, no reduction catalyst installed
SOHIO 3*	Gould			4000	334	.26	10.5	.36	12.1	
					8,032	.27	11.6	.46	12.1	
					16,000	.56	17.0	.74	12.1	
					23,880	.49	7.8	5.94	12.2	
					31,883	.62	20.8	.99	11.1	New EGR valve
					31,969	.45	13.4	1.38	12.8	New Gould converter
					34,853	.42	8.8	.56	14.0	
					40,292	.63	12.6	.77	15.0	
SOHIO 4*	Gould			4000	356	.29	4.0	.53	----	
					1,146	.32	4.1	.52	----	
					9,442	.37	4.3	.77	15.9	Test terminated
					16,098	.54	5.1	2.92	15.4	w/o Gould converter
SOHIO 1**	TWC			4000	492	.26	11.54	1.42	----	
					8,326	.31	10.32	2.12	17.4	
					16,304	.42	12.08	2.22	16.2	
SOHIO 2**	TWC			4000	330	.30	6.54	1.36	----	
					8,107	.36	4.77	2.07	16.8	

* Targeted at 1978 Statutory

** Targeted at 1977 California

in meeting the Federal Standards. The four cylinder data presented would indicate that close control over the EGR rates will be necessary to keep NOx levels below 2.0 NOx.

AMC stated that "we (AMC) are left with little confidence in projecting compliance of any of our 1977 California packages with the certification requirements within sufficient margin to meet the assembly line quality audit requirements". Analysis of the 1977 pre-certification data by EPA during the preparation of this report would indicate that those California systems reported by AMC could have a HC and/or NOx control problems which would necessitate AMC obtaining California's permission for DF line crossing and non-methane standards. Preliminary 1977 certification data also show the same trends.

Additionally, AMC reported that their limited SHED evaporative test data indicates that the 1977 six cylinder vehicles are in the 12 ± 2 gram range while the eight cylinders vehicles are twice these values. AMC will have to do considerable work to lower these values.

Progress and Problems - Post 1977 Model Year

AMC has continued their development work on both the Gould catalyst and three way catalyst systems. AMC also has shown interest in characterizing the sulfuric acid emission levels of their vehicles. However, AMC has confounded their test results from the 1978 durability fleet with investigation of fuels, lubricants and fuel additive packages, and two different air injection configurations while assessing the durability of the advanced catalyst systems. Hence, the true capability of AMC to meet the 0.41 HC, 3.4 CO, 0.4 NOx emission levels may not be assessable due to the differences from the true certification procedure. These tests should, however, enable AMC to narrow the acceptable systems and engine calibration parameters for their next low NOx fleets.

AMC did not report much in the nature of advanced fuel metering or other sophisticated emission control subsystems that could be adapted to their future development vehicles. This is understandable when one considers the fact that AMC buys most of their components from others. The lead time for new technology tends to be somewhat longer when it is not developed in-house.

7.1.2. Chrysler Corporation

7.1.2.1. Systems to be used

Systems to be Used - 1977 Model Year

The Chrysler Corporation will again be recertifying almost all of their engine families in 1977 in order to improve fuel economy over the 1976 models while lowering the NOx emissions to the 1977 levels.

The Chrysler systems for 1977 are described in table Chrysler-1.

Chrysler designates their engines families with a prefix of F for 49-state vehicles and a prefix of C for California vehicles. The 49-state vehicles will continue to use oxidation catalyst and EGR as their main methods of emission control. It is understood that Chrysler will try to introduce Electronic Spark Advance (ESA) in every engine family produced in 1977. They have begun by concentrating on ESA Lean Burn on their larger cubic inch displacement engines in some 1976 models.

Chrysler usually uses the terminology of Electronic Spark Advance (ESA) and Electronic Lean Burn (LB) together, called by Chrysler the "ESA Lean Burn" system.

The term "Lean Burn" has been misunderstood by some in the past and considered as a different engine type. This is not the case. EPA considers the term "Lean Burn" engines to mean conventional homogeneous Otto-cycle engines calibrated to run leaner than stoichiometric.

The ESA part of Chrysler's ESA-Lean Burn is most important, possibly keeping Chrysler a bit ahead of the competition in the introduction of electronics in production automobiles.

Table Chrysler - 1
1977 Chrysler Control Systems

Family	Main Oxidation Catalyst* No. & Size (cu. in.)	Start Oxidation Catalyst No. & Size (cu. in.)	ESA	AIR	Aspirator
	------------ Systems Include	------------			
FD-225-1-A	1-45				X
FD-225-1-C	1-90				X
FD-225-2-A	1-45				X
FD-318-2-C	1-90				X
+FB-318-2-CE	1-90		X		X
FD-360-2-C	1-90				X
FB-360-4-CE	1-90		X		X
+FB-400-4-CE	1-90		X		X
+FB-440-4ST-CE	1-90		X		X
+FB-440-4HP-DE	2-90		X		
CD-225-1-EP	1-90	1-22		X	
ØCD-318-2-GP	1-152	1-22		X	
ØCD-360-4-GP	1-152	1-22		X	
ØCD-440-4HP-FP	2-90	1-22		X	

* All main catalysts have a loading of .01365 gms/cu. in. and start catalyst a loading of .04092 gm/cu. in.

+ No EGR Ø Power Heat Valve

7·13·A

Through the use of ESA, Chrysler has taken a first step toward electronic control of engine operational parameters. The ESA system is intended to replace the existing mechanical and vacuum spark advance control. Spark timing control via a vacuum diaphragm and a centrifugal governor is common on most vehicles today. The ESA is an attempt to tailor the spark advance needed for low emissions and improved fuel economy by sensing various engine operational parameters, including engine speed, engine start, intake manifold vacuum, throttle position, rate of throttle position change, inlet air temperatures, and coolant temperature. Through the use of sensors, the ESA system ascertains the aforementioned operational parameters, and processes the sensor signals with an on-board electronic microprocessor referred to as the Spark Control Computer (SCC). The SCC in turn retards or advances the ignition timing for optimum emission or fuel economy control. The SCC is claimed by Chrysler to be able to discriminate between highway driving (advanced spark for fuel economy) versus city driving (less advanced spark for emission control). The submission from Chrysler did not indicate spark timing conditions at other than the Federal Test Procedures ambient testing conditions.

For the California vehicles, Chrysler will be incorporating a start catalyst to meet the California standards of .41 HC, 9.0 CO, 1.5 NOx. A Power Heat Valve (PHV) to switch the total exhaust flow through the start catalyst on startup will also be used. The system also includes an air pump, air switching for air injection to the exhaust ports at coolant temperatures less than 98°F, and air injection of 90% of the total flow to the downstream location (exhaust manifold flange area) and 10% to exhaust port area at temperatures above 98°F. Additionally, Chrysler California cars have an insulated manifold and upgraded thermal protection to shield the power steering pump from catalyst heat loads. California cars will use EGR and Orifice Spark Advance Control, (OSAC) used last year, plus a new vapor return system for improved fuel evaporative emission control. This new vapor system uses a fuel return line connecting the fuel filter and the fuel tank thereby maintaining a small, constant fuel flow through the fuel pump and tank.

Universal Oil Products (UOP) continues to supply Chrysler with all of their catalysts. Chrysler has reduced the total amount of noble metal used in the main catalysts. The start catalysts have a loading of .029 troy ounces of platinum. Chrysler has dropped the use of palladium for the 1977 model year catalysts, but has indicated they may use ruthenium in some of their start catalysts.

Chrysler projects that the costs for the 1977 Chrysler Federal vehicles will average fifty dollars more than comparable 1976 vehicles. The California vehicles will average 205 dollars due to the production introduction of start catalysts and lower emissions standards. Chrysler projects a fuel economy loss of seven percent from the 1976 model year for Federal vehicles and a sixteen percent loss in fuel economy for the California vehicles. Fuel economy of the 1976 models is compared to other year models in table Chrysler-7. Chrysler estimates if a start catalyst replacement at 25,000 miles on the California vehicles is necessary, the replacement will cost $276.80 for replacement of all catalysts with the labor cost split between $7.20 for start catalyst labor and $100.00 materials costs; and $9.60 labor costs for main oxidation catalyst and $160.00 main catalyst materials costs.

Systems to be used - Post 1977 Model Year

.41 HC, 3.4 CO, 1.0 NOx*

In the Chrysler status report, the discussion of systems targeted specifically to 1.0 gm/mile NOx was relatively limited. Chrysler did state however, that a number of systems which are targeted for .40 gm/mile NOx would also be considered as potential candidates for 1.0 NOx. These systems include dual bed catalyst using a base metal NOx catalyst with or possibly without insulated exhaust manifolds and port liners; the Gould catalyst system, three-way catalyst as a NOx reducer plus EGR;

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*Hypothetical

noble metal on ceramic monolith NOx catalyst plus EGR; three-way catalyst system with EFI or EFM with closed loop control plus EGR, and the Questor Reverter system. These systems will be covered in detail in the next section.

Chrysler did project costs and fuel economy estimates for a typical 1977 Federal V-8 engine targeted for this level based on partial system development and incomplete durability information. They estimate a 360 dollar increase over a comparable 1976 vehicle. The fuel economy penalties are estimated at 12 to 20 percent, relative to 1976.

Systems to be used - 0.41 HC, 3.4 CO, 0.4 NOx

As stated previously, Chrysler reported that all systems targeted toward the 1978 levels would be considered also at the 1.0 NOx level. The principal difference between 1.0 and .4 NOx is apparently exhaust manifold insulation and port liners. Chrysler continues to test and evaluate component systems and has not assembled a full engine system targeted at the 1978 levels. Systems tested to date have generally not been equipped with either the Electronic Fuel Metering, the vaporizing choke, or the Electronic EGR systems which are under parallel development. Chrysler is concerned about model year 1978 because of the uncertainties surrounding the revisions to the Clean Air Act. Chrysler indicated that a decision due to lead time considerations had to be forthcoming soon on what system would be needed in the model year 1978 vehicles.

Low mileage test results of potential components for a 1978 vehicle system begin with table Chrysler-2 which summarizes Chrysler's effort on air switching. Table Chrysler-3 shows the results of other low mileage tests for other potential systems.

Chrysler projected a cost of 445 dollars more than the base 1976 comparable vehicles price. They estimated that the fuel economy penalty would be in the range of 12 to 20 percent. They estimated a maintenance cost of 384 dollars for a catalyst change, at 25,000 miles for both the 1.0 and 0.4 NOx cases. These costs reflect 24 dollars labor, 160 dollars for downstream oxidation catalyst, and 200 dollars for replacement of both NOx catalysts.

Other Systems

Chrysler has undertaken development on a number of other control systems at various levels of efforts. They continue to try to improve their oxidation catalyst by evaluating other types of wash coat or substrates, changes in metal load or composition (substitution of rhodium for some of the platinum), or using lead - resistant combinations (perovskites). With the exception of some preliminary encouraging test results on the perovskite catalysts, Chrysler reports no improvement over their present catalyst for the other techniques tested.

Chrysler continues to work on improved fuel metering or improved engine carburetion. They reported earlier attempts to electronically control the amount of air bled into the main and idle systems thereby lowering the vacuum depression and reducing the fuel flow for the float bowl. Limited testing was reported but no vehicle data was supplied. Chrysler reports that they have continued their work on a Chrysler Electronic Fuel Metering (EFM) system, the results of which, in combination with ESA, can be seen in Table Chrysler - 3. They indicated that this system was a strong candidate for 1978.

Table Chrysler-2

Low Mileage Air Switching System Results

Engine	System	HC	CO	NOx	
225 CID	1976 California development	.35	2.1	1.90	all air to ports
		.33	1.2	1.55	90-10 split*
		6	43	18	% reduction
318 CID	1977 start catalyst developments	.31	1.5	2.31	all air to ports
		.35	1.7	1.90	90-10 split
		-13	-12	18	% reduction
360 CID	1977 start catalyst @ 45,000 miles	.35	4.2	1.25	all air to ports
		.52	5.6	1.11	90-10 split
		-49	-25	11	% reduction

*10% of the air to exhaust ports and 90% of the air downstream before catalyst

Table Chrysler-3
Low Mileage Potential 1978 Components Test Results

Engine	System	HC	CO	NOx	Urban MPG	"Highway" MPG
225-A3	3-way - no air, '75 EGR[*]	.69	10.2	.93	18.2	---
	3-way - no air, no EGR	.53	7.5	2.56	18.2	---
	3-way - air 120 secs. 75 EGR, lean choke	.33	5.0	1.53	18.2	
	Baseline same vehicles	1.40	14.3	3.17	18.5	---
440-A3	EFM/ESA[+]	.96	8.3	1.70	9.43	17.7
	EFM/ESA/OC[+]	.29	2.3	1.60	9.90	18.1
	EFM/ESA/OC/SC[+]	.29	2.1	1.25	9.90	17.8
318-A3	cold start electrical fuel vaporizer[Ø]	1.01 gms	2.56 gms	---	---	---
	standard 1976 (Fed)	1.79 gms	23.6 gms	---	---	---
	standard 1976 (Cal)	.56 gms	8.73 gms	---	---	---
360-A3	dual catalyst w/EFM[**]	.41	2.62	.48	11.60	---
	same as above w/Chrysler	.37	1.79	.44	---	---
	metallic NOx cat. substituted for DuPont cat.	.40	2.20	.64	---	---
360-A3	dual catalyst w/dual parallel, insulated oxidizer	.24	3.60	.90	11.1	---
	dual catalyst w/single oxidizer	.32	3.93	.85	11.3	---

[*] Targeted at .41 HC, 1.5 NOx

[**] DuPont Perovskite Ruthenium Reduction Catalyst

[+] No EGR

[Ø] W/ESA, port liners, Test results for first 32 secs. after start, Bag 1

One feature of the EFM system is a new air measurement technique which Chrysler claims to be more accurate than other known methods of inlet air measurement, including the laminar flow elements used in research and development work. The principle incorporates a vortex precessor and measures current in a sensor to precisely measure air flow. A comparator is used to measure and compare both fuel and air flow for close control of the air/fuel ratio. The details of the system were not reported. Similar devices have been reported in the literature.*

Chrysler has tested the Dresserator vs. standard and advanced carburetors during the past year. The Dresserator system shows a range of 3 to 26% average reduction in BSHC, an average 14 to 22% reduction of BSNOx, and an average 4 to 16% reduction in BSFC. Based on these promising engine dynamometer tests, Chrysler will continue evaluation of the Dresserator system.

Although some test results of the vaporizing choke were reported (see Table Chrysler-3), test results with this potentially attractive subsystem incorporated into a complete emission control system, targeted for low levels, have not been reported. Such tests are planned for the future.

Single-cylinder experiments were conducted to investigate the effect of insulation on the inside of the combustion chamber. The purpose of the insulation is to reduce the transfer of heat from the cylinder wall and hence reduce the quenching of hydrocarbons at or near the cylinder wall. Two insulating materials were tried; flame sprayed zirconia and a polymide resin made by DuPont. The resin failed after 29 hours of single cylinder operation with the exception of that on the intake valve surface but did reduce hydrocarbon emissions by 25%. The zirconia insulated engine produced a 30-40% reduction of hydrocarbons with good durability. Chrysler plans to conduct multicylinder testing of both the zirconia coated surfaces and intake valve only coated with the polymide coating. The principal interest in the polymide is lower cost, plus ease of application. Zirconia plasma spraying is considered an expensive process, according to Chrysler.

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*Promising Newcomers for Tough Flow Measurements, by Gilbert Kivenson in Machine Design, January 8, 1976 page 80.

Chrysler will introduce in 1977 a two piece aluminum intake manifold not so much for emission reduction but for weight reduction.

There continues to be activity at Chrysler to develop input devices for sensing engine parameters and changes in parameters which eventually could be controlled by a central computer processor. Devices which have been researched or tested include: an electronic choke control for more rapid choke removal to reduce cold start emission levels and improve cold driveability; a series of low cost exhaust gas sensors, both vendor supplied and Chrysler developed with the objective of low OEM cost (under 3 dollars), closed loop feedback engine controls, and O_2 sensors, though they did state O_2 sensors were not a prime candidate for 1978. Chrysler is also looking at automatic idle speed control to provide constant idle speed regardless of engine load. Work in the above areas is apparently in the early stages, since no vehicle data were reported.

Further testing to evaluate various NOx catalyst and NOx catalyst materials was reported by Chrysler. They have tried to stabilize various ruthenium catalysts. One vehicle in durability testing showed a factor of two increase of NOx emissions after 16,000 miles of durability. Chrysler has returned this catalyst to the laboratory for further developments. However, zero hour testing of a DuPont ruthenium perovskite NOx catalyst looks promising and has been scheduled for vehicle testing shortly.

Chrysler reported continued research and evaluation of their improved NOx metallic catalysts. They were able to improve the performance of the metallic catalysts by increasing the temperature. The results from a vehicle equipped with this catalyst (MR23AC') is reported in Table Chrysler-4 at zero miles to 20,000 miles. The system failed after 20,000 miles, and Chrysler is unable to determine the cause of failure. They will start a new vehicle on durability shortly.

Work has been temporarily suspended at Chrysler on the Gould system vehicle after an unacceptable increase in pressure drop across the NOx catalyst resulting in an increase of emissions after 15,000 durability miles. Gould has inspected the vehicle and plans are underway to return the vehicle to test. The mileage results are noted in the table Chrysler-5.

Table Chrysler-4
Dual Bed Catalyst System with Metallic NOx Catalyst
360 CID, 5000 IW, Port Liners, No EGR,
Insulated Exhaust Manifolds, Automatic Trans, Air Switching*

Mileage	HC	CO	NOx	CO_2	Urban MPG
Baseline	.28	4.4	.30	804	10.93
5000	.33	2.4	.34	781	11.29
10,000	.27	1.2	.20	736	12.02
15,000	.33	2.2	.26	776	11.36
20,000	.68	4.1	.20	741	11.84
20,000	.32	2.5	.36	741	11.90
Comparable vehicle**	-	-	-	-	10.1 to 11.4
" "	-	-	-	-	10.1 to 12.9
" "	-	-	-	-	11.6 to 13.4
" "	-	-	-	-	10.5 to 11.6

* 63.2 mg/mile H_2SO_4 on the sulfate emissions cycle, fuel sulfur level unreported.

**1976 durability certification vehicle

Table Chrysler-5

Dual Catalyst System with Gould Metallic NOx Catalyst

360 CID, 5000 IW, 19 CID Air Pump, GEM 68

O_2 Getter, Chrysler (70/30) Oxidation Catalyst

Mileage	HC	CO	NOx	Urban MPG
Baseline	.22	3.2	.91	10.20
5,000	.45	6.1	.95	10.80
10,000	.45	16.6*	.89	10.50
15,000	.51	3.4	1.31	11.30
Comparable vehicle**	-	-	-	10.1 to 11.4
" "	-	-	-	10.1 to 12.9
" "	-	-	-	11.6 to 13.4
" "	-	-	-	10.5 to 11.6

*Possible Air Pump Failure, results after air pump reinstallation .31 HC, 2.1 CO, .88 NOx, 10.70 F.E.

**1976 certification durability vehicle.

The target levels of .41 HC, 9.0 CO, and 1.5 NOx were used to evaluate various dual catalyst system candidates. The first combination tested was a mini-NOx dual catalyst set-up. This was a 20 cu. in. oxidation catalyst coupled to a 45 cu. in. metallic reducing catalyst followed by a 90 cu. in. oxidation catalyst. These are the first results listed below the baseline numbers in Table Chrysler-6.

This system was replaced with a Chrysler metallic NOx reducer only, and finally the system was modified to incorporate EGR and a 58 cu. in. close coupled NOx catalyst. Testing continues on these systems.

Table Chrysler-6
Mini NOx Dual Catalyst System

Systems	HC	CO	NOx	F.E.
Baseline 75 Cal.	.41	4.0	1.65	15.1
Mini-Ox Nox	.25	4.1	1.74	17.0
90 in^3 (Chrysler)	.29	3.3	1.13	15.7
20 in^3 DuPont perovskite + 38 in^3 200/0 Pt ox. cat.	.32	3.4	.85	14.3

Work on the Questor system has been suspended while a new third generation system is being prepared for Chrysler by the AP Parts Co.

Chrysler continues to evaluate various EGR systems for application at a level of 1.0 NOx. They have tested the Bendix Flow Control System and reported no improvement over the venturi-vacuum amplified system they presently use, either for emissions or driveability. They also report that the exhaust back pressure EGR systems they have tried are not superior to their own system. They did comment that they are trying to improve and reduce cost in their present EGR system, and are working on an electronic, programmable, EGR prototype system which has not been tried on a vehicle yet.

They have tested the Ethyl Turbulent Flow Manifold and port liners. They reported that while there was an improvement in emission levels during the initial acceleration of the LA-4 driving trace, indicating better warm-up, there was a modest reduction in overall emission levels for HC, CO and a corresponding increase in NOx. They further feel that EGR must be added to this system to reach full potential.

Chrysler's efforts on Honda type stratified charge engines has ceased as a consequence of the economic cutbacks of November 1974. They have also abandoned their cooperative efforts with the Texaco Corporation using the TCCS stratified charge engine. Chrysler mentioned that no attempt was made to see if the Army funded work on the TCCS system was of any potential for passenger car evaluation.

Chrysler is Dieselizing a 225 cu. in. engine for evaluation for a passenger application. They have a consulting contract with Ricardo for this study. The first engine will be built in May, 1976.

An investigation sponsored by ERDA continues into improving the gas turbine for vehicle application. Work also goes on with both rich and lean thermal reactor systems, but Chrysler indicates that they feel neither of these systems have potential for meeting 1978 standards in 1978.

Chrysler places great emphasis on the vehicle weight reduction for primarily fuel economy and some limited emissions improvements. The weight reduction program cuts across all corporate levels, and is an example of extra effort and cooperation needed to meet government mandates, in this case primarily for fuel economy.

7.1.2.2. Durability Testing Programs

Durability Testing Programs - 1977 Model Year

Chrysler is now partially through 1977 certification with the Federal cars experiencing no major problems. Some of the California cars apparently are going to line cross, especially on HC. Preliminary data show that fuel economy for the durability cars is about the same as the '76 cars.

Durability Testing Programs - 0.41 HC, 3.4 CO, 1.0 NOx

For the .41 HC, 3.4 CO, 1.0 NOx level, Chrysler has not assembled a fleet. The only fleet testing reported was a start catalyst sort fleet of six cars for 1977 start catalyst selections and a small aspirator design and test fleet for Federal 1977 model year vehicles.

Durability Testing Program - 0.41 HC, 3.4 CO, 0.4 NOx

At levels below 1.5 NOx Chrysler reported modest progress on evaluation of reduction catalysts. They have increased the number of systems under evaluation, but have not reported any substantial durability mileage accumulation with the exception of the metallic base reduction catalyst which ran 20,000 miles before failure. Chrysler has plans to initiate vehicle durability test programs on only those system which present the most promise.

7.1.2.3. Progress and Problem Areas

Progress and Problems - 1977 Model Year

Chrysler will be introducing two major new emission control techniques in their 1977 model year lines. These system will be the Electronic Spark Advance system plus aspirator for the larger cubic inch displacement Federal vehicles. The system may also be included on other models, except the 225 cu. in. engine families. The start catalyst system for vehicles is the major addition for California vehicles.

After initial start catalyst sort fleet testing, it was decided to go into the certification cycle without durability testing of the most promising start catalyst. The ESA system has undergone durability testing for a late certification on a 1976 vehicle which is proposed for 1977 carry over. There should be relatively few problems encountered with the ESA vehicles during 1977 certification process. The addition of the aspirator system to 1977 Federal vehicles may have been the result of Chrysler's problems in passing idle inspection tests conducted in several cities in various Air Quality Regions. The inclusion of an aspirator could help reduce idle CO emission levels.

Progress and Problems - Post-1977 Model Year

The major problem which remains both at the hypothetical level of 1.0 NOx and the 0.4 NOx emissions levels, has been the lack of total system testing aimed at either of these goals. While Chrysler has performed advanced component testing, they have not tested complete systems with these components integrated. Chrysler has maintained that the uncertainties as to the emission control standard for the post-1977 model year and the lead time to develop and assemble all of the components of a full system has prevented them from testing fully integrated systems.

The work reported by Chrysler on the electronic control of the engine, engine sensors, and metallic reduction catalysts shows that they are one of the leaders in those areas. The durability, cost reduction, and maintainability of these systems remains to be proven in the field. Chrysler has made further progress in the areas of catalyst screening both reduction and oxidation, use of perovskite catalyst materials, electronic controls of engine parameters, and heat retention techniques for increasing catalyst efficiencies.

Chrysler's view of the progress being made toward meeting low emission levels in the near term was generally somewhat gloomy, especially with respect to the fuel economy impacts.

Considering a longer lead time, however, Chrysler's statements are somewhat different. Commenting on the JPL report*, they stated the following:

> "The internal combustion engine has become the proven workhorse for vehicular propulsion for over seven decades and a great deal of effort and money is going to be required to develop a successor that can match or exceed its capabilities, particularly in light of probable future improvements. In this regard we agree that given adequate time for development, cars equipped with Otto engines can be improved to meet J.P.L.'s assumptions for emission requirements and also provide improvements in fuel economy. (J.P.L.'s emission requirement assumptions are 0.4, 3.4, 2.0 nationally and 0.4, 3.4, 0.4 for the L.A. basin only)".
>
> "The J.P.L. report refers to the standard spark ignition engine as the U.C. Otto. Their Mature version of this engine is presumed to be of a reciprocating configuration, either 4 cylinder in line, V6 or V8 depending on engine size, J.P.L. assumes that this engine will be capable of 5% lower BSFC than the best of the 1975 engines through improvements in the induction system, and more over capable of meeting the .4g/mile NOx level using only a 3-way catalyst regardless of vehicle size.
>
> Based upon Chrysler's experience to date, this latter assumption is overly presumptive and could lead to

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*CHRYSLER CORPORATION COMMENTS ON THE JPL EVALUATION OF ALTERNATIVE AUTOMOTIVE POWER SYSTEMS, the attachment to a letter from Mr. S. L. Terry, Vice President, Public Responsibility and Consumer Affairs, Chrysler Corporation, to Mr. N. E. Stoney, Department of Transportation, October 16, 1975, (quotes from pages 1 and 5 of the attachment).

> erroneous conclusions regarding future developments because at this time we know of no system, including the 3-way catalyst that is capable of meeting these standards. We agree that the low emissions target will eventually be met, but the exact nature of the system and the time to develop it are still unknown."

Fuel Economy Analysis

Analysis of Table Chrysler-7 would seem to indicate that the Chrysler projected fuel economy penalties may be very pessimistic compared to the 75/76 low mileage durability vehicles. There appears to be no indication of the large fuel economy penalties that were projected. Chrysler apparently reported to CARB that they do not expect major fuel economy penalties for the California vehicles. EPA concludes that there will be no fuel economy penalty for the Chrysler vehicles in 1977 model year.

Table Chrysler-7
Fuel Economy Comparison of Chrysler Models

				75/76 Fed Dur. Veh.			75/76 Cal Dur. Veh.			Prototype					
Model	Eng	Trans	IW	VIN	5000 mi MPG	Range 4K-50K	VIN	5000 mi MPG	Range 4K-50K	VIN	Target Std.	5000 mi MPG	% Change from Fed	% Change from Cal	Range
A-body	225	A3	3500	---	---	---	4008	15.0	14.1-16.2	---	---	---	---	---	---
	225	A3	4000	4001	14.5	14.4-15.8	---	---	---	140*	4	14.9	+0.6	---	14.2-15.0
				4018	15.1	14.9-15.8	---	---	---	158*	5	13.7	-7.4	---	13.7-15.0
										623**	4	17.0	+14.9	---	---
										623**	4	15.7	+6.0	---	---
										623**	4	14.3	-3.4	---	---
B-body	318	A3	4500	2024	10.6	9.7-10.9	4020	11.0	10.6-12.4						
				4019	13.0	12.4-13.8	---	---	---	377*	4	12.8	+10.0	+16.3	11.1-13.3
				4020	11.0	10.7-12.4	---	---	---	633**	4	12.1	+5.1	+10.0	---
										633**	4	13.0	+13.0	+18.2	---
										633**	4	11.7	+1.5	+5.3	---
C-body	360-4	A3	5000	---	---	---	2003	10.2	10.1-11.4	666*	4	10.5	---	-3.6	10.6-11.2
				---	---	---	4010	11.1	10.5-11.6	545+	1	11.3	---	+3.6	10.9-13.2
	360-4	A3	4500	4028	11.7	10.5-12.0	---	---	---						
	360-4	A3	4000	2016	11.2	10.5-12.2	---	---	---	178ø	1	11.1	---	+2.7	10.5-11.4
C-body	440	A3	5500	4005	9.9	9.1-10.5	2031	9.2	8.9 - 9.3	748*	4	9.1	-8.1	-3.3	8.4-9.7
							2031	9.2	8.9 - 9.3						

Note: Target Standard Code

1.5/15/2.0 = 6
0.9/9.0/2.0 = 5
.41/9.0/1.5 = 4
.41/3.4/2.0 = 3
.41/3.4/1.0 = 2
.41/3.4/0.4 = 1

* Start catalyst follow-up fleet

+ NOx catalyst vehicle (MR-23AC')

ø Gould catalyst vehicle (did not meet target)

** Dual catalyst system - low mileage results

1. with MR-23AC' replacing NOx cat and ox.cat.
2. EGR + pervoskite NOx catalyst and ox. cat.
3. MR-23AC' catalyst both sides.
4. No. 3 plus leaner idle.

++ Electronic Lean Burn - 76 California used for 77 Federal

7.1.3 Ford

7.1.3.1 Systems to be Used

Systems to be Used - 1977 Model Year

Ford is fielding an exceptionally large durability fleet for 1977. Compared to 29 engine families for 1976, Ford is now accumulating durability mileage on 110 family systems for 1977. The nine basic engine displacement sizes all have a multitude of variations. While the entire line of 1977 systems include oxidation catalysts and EGR, Ford is running all of engine displacement sizes with AIR and non AIR systems. Seven different catalyst volumes are featured, ranging from 80 to 190 cubic inches. Ford uses monolithic catalysts exclusively. The majority of the 49 state systems will include exhaust backpressure modulated EGR for 1977 as opposed to the ported and venturi vacuum amplified types formerly used. Ford reports that the catalyst formulation is also improved. California systems will feature larger catalyst volumes, high energy ignition and backpressure EGR exclusively to meet the .41 HC, 9.0 CO, 1.5 NOx level for 1977. Nine different engine family systems are calibrated for high altitude certification. The carburetors, EGR and transmission selections for these cars are tailored for high altitude. Ford is not using systems such as aneroid carburetors that automatically compensate for altitude. Ford estimates that the retail cost increase for the 1977 models over the 1976 models to be $15 to $25 for the 49 state system and $100 to $150 for the California system.

A brief review was made of the preliminary emission and fuel economy results for Ford's 1977 certification durability vehicles. Only those cars that had completed their 50,000 miles were reviewed. Ford did not specifically identify which cars were Federal models and which cars were California models, but this could be generally determined from the emission results. The emissions of the 1977 California systems showed frequent line crossing for HC and NOx, which in the future may be permitted by California regulations. The fuel economy of the 1977 California durability vehicles was generally equivalent or superior to comparable 1976 California durability vehicles for the vehicles studied.

Systems to be used - Post-1977 Model Year

Ford has identified the following components as prime constitutents of systems intended for the .41 HC, 3.4 CO, 0.4 NOx level in the 1978 time frame:

a. Conventionally controlled ignition and EGR (probably high energy and exhaust backpressure modulated, respectively).

b. Three-way catalyst with programmed secondary air and oxidation catalyst.

c. Mini warm-up catalyst for some engine applications.

d. Improved carburetion (better A/F control).

e. EGR cooler (some applications).

f. Larger exhaust manifolds.

The additional cost of the 1978 system is estimated by Ford to be approximately $260 to $360. Ford cautions that this price would rise if a catalyst change proved to be necessary.

Ford emphasizes that meeting the statutory levels (0.41 HC, 3.4 CO, 0.4 NOx) in 1978 will preclude them from using several preferred systems now under development. These preferred systems are integrated electronic controls for spark advance and EGR, along with feedback controlled carburetion.

The best emission results presented by Ford with a system closely resembling their prime 1978 system were 0.28 HC, 0.94 CO and 0.59 NOx at 4,000 miles on a 3500 lb. inertia weight vehicle with a 302 CID engine. This car was reported to have been calibrated for 1.0 NOx rather than 0.4 NOx. The only three-way catalyst testing reported by Ford that was actually calibrated for 0.4 NOx involved 2.3 liter Pinto engines equipped with Bosch L-Jetronic electronic fuel injection and closed loop feedback control of A/F ratio. Five different three-way catalysts were dynamometer aged and periodically installed on a slave vehicle for CVS testing. The best results were with a Degussa catalyst and are shown in Table Ford-1.

Table Ford-1

Dynamometer Hours	Equivalent AMA Miles	HC gm/mi	CO gm/mi	NOx gm/mi	Fuel Economy mpg urban
30	3,750	0.24	3.01	0.09	21.2
	4,000	0.16	2.28	0.17	21.4
200	25,000	0.25	2.10	0.25	21.3

As a comparison, Ford ran two 3000 pound IW 2.3 liter Pintos for 1976 certification durability. At 25,000 miles their urban fuel economy values determined by a least squares fit were 17.6 MPG and 16.7 mpg. This least square fit is considered more representative than the actual data, since the actual data for one of the cars, was probably an outlier on the low side at 14.1 mpg. This does not necessarily mean that there is going to be a 21 to 28 percent improvement in fuel economy with systems targeted for 0.4 NOx, because there are confounding effects i.e. slave vehicle, non AMA durability, less than 50,000 miles, etc. However it is safe to conclude that the large fuel economy losses predicted by some manufacturers for this emission control level may vanish with continued development.

Systems to be used - Alternate Levels

Ford has begun a development program targeted at the .41 HC, 3.4 CO, 1.0 NOx level. Two approaches are being evaluated on 3500 lb. inertia weight vehicles using 302 cu. in. engines. The first, called the HC/CO system controls HC and CO with oxidation catalysts and controls NOx with a relatively sophisticated EGR and spark control system. The HC/CO system includes cooled EGR and secondary air. The second system is a three-way catalyst system which employs an oxidation catalyst downstream of the three-way catalyst for supplemental HC and CO control. Back-pressure EGR and secondary air ahead of the oxidation catalyst are also included. Three HC/CO systems and two three-way catalyst systems have been built and run on durability for 4,000 miles. Table Ford-2 shows the best performing cars for each system.

Table Ford-2

System	HC	CO	NOx	Urban F.E.	Highway F.E.
HC/CO	0.21	1.58	0.74	11.5	17.0
Three-Way	0.30	2.10	0.51	15.4	--

Three comparative 1976 durability cars are available for comparison. Their 5000 mile urban fuel economy values were 9.2 mpg, 12.5 mpg and 10.4 mpg. The other 1.0 NOx development cars had urban fuel economy values of 10.5 mpg, 11.8 mpg and 15.0 mpg. On balance, the lower emission vehicles showed superior fuel economy.

The above test data suggest that the engine calibrations used on the HC/CO system utilizes engine calibrations that result in an urban fuel economy penalty, compared to the 3-way car.

Other Systems

Ford reports both vehicle and engine dynamometer testing of the Gould GEM 68 Getter system. The emphasis was on the dynamometer testing, with Ford pursuing an extensive evaluation effort to determine the fundamental relationships of conversion efficiency with exhaust gas temperature, air to fuel ratio, exhaust gas flow rate, etc. Ford concluded from this evaluation that: the NOx conversion efficiency of the Gould system is low at temperatures below 1100°F; the NOx catalyst is susceptible to sulfur poisoning; and the NOx conversion efficiency decreases with decreasing NOx concentration. These temperature results conflict with Gould's in-house testing and Gould and Ford have discussed the details of Ford's testing technique. Further evaluation testing will be performed by Ford.

The vehicle portion of Ford's testing has not made much progress. The Gould system is installed on a 1975 LTD with the 400 cu. in. engine at 5000 IW and a single 95 cu. in. Englehard PTX IIB oxidation catalyst downstream of the NOx catalysts following the exhaust pipe Y. This oxidation catalyst installation appears less than optimum for emissions control since on their 1977 certification fleet, Ford is running two oxidation catalysts on all of their 5000 IW 400 cu. in. engined vehicles. Depending on the particular engine family calibration, these catalysts range from 132 cu. in. to 190 cu. in. each. Also, the PTX IIB has been succeeded by the PTX IIC which has significantly improved performance and was run by Ford in their Fleet B testing. The non-optimal nature of this installation is evident in Ford's test results. The most recent 1975 FTP's (two test average) showed 1.07 HC, 9.0 CO, 0.47 NOx with 10.3 urban miles per gallon. Ford's two 1975/76 durability cars at the same

IW with the same displacement engine had 9.0 mpg and 9.3 mpg urban fuel economy values at 5000 miles. Their HC and CO levels were lower than the dual catalyst car and their NOx values were 3 to 4 times higher.

Ford reported further testing of the 2.3 liter Pinto equipped with the Questor emission control system. This car demonstrated .06 HC, 2.36 CO and 0.22 NOx in early testing but emissions rose sharply in the first 400 miles due to insufficient secondary air supply. Questor improved the air supply and switched to a higher temperature alloy for the reverter. Testing at Questor of the modified system gave emission figures of 0.11 HC, 2.74 CO and 0.32 NOx with 18.4 mpg. Subsequent Ford testing showed a three test average of 0.11 HC, 3.24 CO, 0.44 NOx and a fuel economy of 17.66 mpg. Ford points out that a 1976 2.3 liter Pinto achieved 22.4 mpg during EPA certification. However, their durability cars at 5000 miles were 17.3 and 16.9 mpg. Further durability testing was conducted but at approximately 5000 miles weld failures were experienced in the reverter causing CO and NOx control to deteriorate.

Ford reports development progress on several promising components and systems. For the most part these systems, discussed below, will not be available until after the 1978 model year, according to Ford.

Computer Controlled Timing (CCT) is a sophisticated ignition control system which in theory can provide near optimum spark timing strategies. This is accomplished by monitoring pertinent engine, vehicle and atmospheric variables with electrical transducers. This information is fed to an on-board computer which determines the optimum spark timing based upon its programmed logic. Successfully applied, this concept can improve fuel economy and performance while reducing emissions. In addition, there is the potential for combining CCT with electronic EGR and fuel metering control. Ford reports that they are now working out timing strategies for CCT through engine mapping studies and pushing forward development of the necessary hardware and sensors. The major hurdle to be overcome is the development of accurate, reliable and inexpensive transducers, according to Ford.

Ford is pursuing the development of three different sonic carburetors. Along with the Model III Dresserator, Ford is developing two configurations of its own. The Dresserator and one of the Ford versions are the sliding jaw variety. The other Ford is a hinged jaw. The significant feature of the Ford versions is the fact that both employ electronic fuel metering (EFM). The hinged jaw version employs injectors which spray into the air section. The Ford sliding jaw configuration retains the more conventional nozzle bar of the Dresserator carburetor for introducing fuel into the air section. In addition to more precise fuel metering and the resultant improvement in fuel air ratio control, EFM can be integrated into Ford's electronic spark and EGR controls. Closed loop exhaust gas sensor control is also a possibility, which would lend itself to a three-way catalyst system. Ford reported that the emissions of a 4500 lb. inertia weight Torino equipped with Ford's sliding jaw sonic carburetor were 1.4 HC, 5.1 CO, 1.8 NOx with an urban cycle fuel economy of 11.2 mpg. This was without EGR, catalyst, or AIR. Because of required further development and anticipated retooling time, Ford estimates that their hinged jaw and sliding jaw versions could not be introduced before 1979 and 1980-1981, respectively.

Another approach reported by Ford that is aimed at improving fuel distribution and vaporization is the vapor carburetor. Still in the early research phase, this concept utilizes exhaust gas heat to vaporize the fuel and accomplishes metering through a differential pressure regulator. Cold start fuel vaporization uses electrical heating of the fuel. Ford's information on this concept was rather sketchy, but they did project data showing emissions equivalent to those obtained with electronic fuel injection, with improved fuel economy.

Ford reported the initiation of a lean burn engine development program. Their work to date has been aimed at determining the potential improvements in emission control, fuel economy and driveability that could result from this approach. Their engine displacement/inertia weight families have been modified with lean burn components and tested at different emission level targets. The engine families involved were the 2.3 liter Pinto, the 250 cu. in. Granada and the 400 cu. in. Torino. The components consisted of modified intake manifolds with improved distribution and increased intake charge heating, exhaust port liners for exhaust heat conservation and larger exhaust manifolds or exhaust reactors to promote after reaction oxidation of HC and CO. The engines were then leaned out to 17-18:1 A/F ratio. Oxidation catalysts and EGR were included in the systems depending on the emission levels sought. The vehicles were then calibrated for emission levels ranging from .4 HC, 3.4 CO, 2.0 NOx to 1.5 HC, 15 CO, 3.1 NOx.

Limited test results were reported but one of the better performing installations was a 2.3 liter Pinto which was equipped with port liners, exhaust reactor and no catalyst or EGR. This vehicle was targeted for .9 HC, 9 CO, 2.0 NOx and it achieved .43 HC, 4.98 CO, 1.5 NOx at low mileage. This program is an example of good emission control technology via engine modifications not being incorporated into a "full effort" system. While it is realized that the purpose of the program was to investigate "lean burn" technology, and the systems were probably considered by Ford to be non-catalyst alternates at higher emission levels, it would have been valuable to learn the capability of this system combined with oxidation catalysts. Nevertheless the system demonstrated potential for achieving low emissions and should be integrated into the type of full effort system the manufacturers' will require for optimization of both fuel economy and emissions.

Other vehicle development activity is underway at Ford and, for example, they reported 0.37 HC, 1.84 CO, and 1.37 NOx for a 2000 lb inertia weight vehicle with 26.3 urban fuel economy and 36.3 highway fuel economy.

Some relatively promising development progress was reported for the PROCO (Programmed Combustion) engine, Ford's stratified charge engine. Ford has been experimenting with faster injection rates, and based upon preliminary work, forecasts that a 50% reduction in NOx is achievable. This was stated in Ford's critique of the Jet Propulsion Laboratory report "Should We Have A New Engine". Ford indicates that this results in a predicted 20 to 25% fuel economy advantage for the PROCO over a controlled uniform-charge Otto engine (conventional spark ignition engine) at the .41 HC, 3.4 CO, 0.4 NOx level. Work to date on the fast injection rate has been limited to single cylinder engine testing. Fuel distribution and injection system durability problems may be encountered in more complex multi-cylinder installations. Ford also reported investigative work on torch ignition, improved fuel spray atomization and combustion chamber studies to reduce HC.

Ford reported emission and fuel economy performance for three 400 CID PROCO vehicles targeted at specific emission levels. This data is shown in Table Ford-3. Urban cycle fuel economy of comparable 1976 conventional Ford models is approximately 10-12 mpg.

With respect to their "fast burn" engine development program Ford reports disappointing results. Ford's objective was to achieve a 100% increase in the speed of combustion. In theory, the higher combustion speed should have resulted in lower octane requirements, increased EGR tolerance, lower NOx levels and better lean mixture tolerance. Instead of a 100% increase, Ford actually achieved only a 25% increase in the rate of combustion and the NOx control has been less than expected. The octane requirement actually increased. However, Ford appears to have confidence that they have diagnosed the problems and are embarking on a test program to verify their proposed fixes.

Table Ford-3

400 cu. in. PROCO without Catalysts 5000 lb I.W.

	HC	CO	NOx	HC	CO	NOx	HC	CO	NOx
Calibration level	.9	9	2.0	.4	3.4	2.0	.4	3.4	1.5
Feedgas objectives	2.2	40	1.6	1.1	14	1.6	1.1	14	1.2
Actual	1.9	12.5	1.2	1.2	13.3	1.5	1.7	19.2	1.2
Fuel Econ. (MPG)									
Urban	14.4			12.7			13.3		
Highway	19.0			18.8			18.8		

Fuel Economy

Ford supplied very little information on programs aimed specifically at improving fuel economy. Ford explained that this information "need not be discussed in detail in an emission control status report".

The only specific fuel economy improvement programs described by Ford were lower numerical rear axle ratio and lower power to weight ratio studies. Ford reported that as the numerical axle ratio is lowered 0.25 the average highway fuel economy is improved by approximately 1.0 mpg and the average urban fuel economy is improved by about 0.1 mpg. However this axle ratio change increases HC and NOx by approximately 8% and 3%, respectively. CO was reduced by about 2%. This degradation of HC and NOx control along with worsened driveability may limit the use of this technique.

Reduced power to weight ratio was reported to result in a 0.8 and 1.0 mpg improvement in city and highway fuel economy respectively. Ford explains that the limiting factor on the utilization of this technique is the increase in NOx that is experienced as BMEP goes up. The negative implications of this technique can be improved somewhat by properly tailored EGR.

Durability Testing Programs

Durability Testing Programs - 1977 Model Year

Ford completed mileage on their 1977 Improved Catalyst Technology Fleet B in June 1975. These cars were calibrated to comply with a .41 HC. 3.4 CO, 2.0 NOx level. Nine different substrate/noble metal formulations were tested on a total of 35 vehicles. Fifteen vehicles completed the target of 50,000 miles. The vehicles received periodic servicing to maintain exhaust feedgas levels which is not allowed under EPA certification procedures. The best performance in terms of 50,000 mile HC conversion efficiency was a 268 cubic inch Englehard IIC formulation on a Grace 400 substrate. This catalyst showed HC and CO conversion efficiencies of approximately 77% and 86% respectively, at 50,000 miles. The Fleet B testing was done with fuel complying with the minimum contaminant levels formerly specified by EPA.

Ford has indicated that with the revised certification fuel, the Fleet B-type oxidation catalysts would have had improved conversion efficiency. They indicated that a 70% efficient catalyst using the old fuel might be improved to 75 to 77%, with the new fuel. Considering the best Fleet B catalysts, it is concluded that catalyst efficiencies of at least 80% for HC at 50,000 miles are likely to be obtained in the near future with continued development.

Table Ford-4 lists and compares the urban fuel economies of the Fleet B cars and comparable 1976 models. The data for the 1976 models comes from the official certification durability cars. The Fleet B results for the 5000 mile fuel economy are averaged for each model. The Fleet B vehicles have poorer fuel economy than the 1976 certification durability cars.

Table Ford-4

Urban Fuel Economy of Fleet B and Comparable 1976 Models

Model/Displacement	IW	5K	FE Range for 50K		Type	5K	FE Range for 50K		Percent Change in 5K F.E. from 1976 to Fleet B
			Low	High			Low	High	
Pinto 2.1 liter	3000	16.2	14.8	17.9	Cal.	17.2	17.0	18.1	-6.2
Mustang 2.8 liter	3500	13.2	12.8	15.5	Cal.	14.7	13.6	16.3	-10.2
Maverick 250	3500	14.0	12.4	17.1	Cal.	14.8	13.5	15.4	-5.4
Maverick 302	4000	10.1	8.8	11.6	Fed.	10.4	7.8	11.0	-2.9
Torino 351	4500	9.1	9.0	10.1	Fed.	10.2	9.3	11.3	-2.2
Ford 400	5000	9.2	8.1	13.9	Cal.	9.0	8.2	9.2	+2.2
Mercury 460	5500	9.9	8.5	12.5	Fed	8.8	7.8	10.8	+12.5

Durability Testing - Post 1977 Model Year

Ford has started six vehicles calibrated at .41 HC, 3.4 CO, 1.0 NOx on a 50,000 mile durability test. All of the cars are equipped with three-way catalysts with supplemental oxidation catalysts downstream of the three-way catalysts. The systems include conventional (non-feedback) 2150 carburetors which have been calibrated at stoichiometry. The cars are also equipped with backpressure EGR and secondary air for the oxidation catalyst. The cars are 3500 lb inertia weight vehicles using the improved 1977 model 302 engine. Three of the cars will receive periodic maintenance in an attempt to partially simulate feedback air/fuel ratio control. The car with the highest reported mileage (15,000) at time of Ford's report was measured at .31 HC, 2.00 CO and 0.39 NOx with a fuel economy of 15.1 mpg.

Progress and Problems - 1977 Model Year

Going into certification for the 1977 model year, Ford is well prepared with system selection and testing well established. All models will have full catalytic treatment of the exhaust gas and Ford now has it's high energy ignition and backpressure EGR in production. Improved catalyst technology, however, is where Ford stands out. Larger catalyst volumes may also be used on some models.

Progress and Problems - 1978 Model Year

Fords designation of the three-way catalyst plus oxidation catalyst approach as their prime system to meet the .41, 3.4 CO, 0.4 NOx standard in 1978 illustrates their preference for the 3-way approach. Three-way plus oxidation catalyst type systems may be considered inferior by some in the near term to dual catalyst systems in meeting the .41 HC, 3.4 CO, 0.4 NOx level, but Ford is more bullish on the 3-way than others. Ford can now be considered to have one of the most aggressive 3-way catalyst development programs in the industry.

7.1.4. General Motors

7.1.4.1. Systems to be Used - 1977 Model Year

The General Motors (GM) systems for 1977 Federal certification vehicles will use a variety of technical options as shown in table GM-1. Early fuel evaporation (EFE) will be used to varying degrees by all divisions except Oldsmobile. Buick, Cadillac, and Oldsmobile will almost exclusively use the backpressure (BP) exhaust gas recirculation (EGR) system. Chevrolet and Pontiac will retain the ported (P) EGR system. The only Federal vehicles to use conventional air injection (AIR) systems will be the fuel injected models. The 140 CID models will use the reed valve (R) AIR system which GM calls "Pulse Air". Oldsmobile apparently will certify some models with both mechanical/vacuum (M/V) spark control and electronic (E) spark control. The 160 and 260 cubic inch, pelleted, oxidation catalysts will again be used, though many 260 converters will have their noble metal loadings increased from .05 (formerly used for both the 160 and 260) to .08 troy ounces of 71% platinum/29% palladium. GM apparently will later attempt to certify at least one family at a .04 troy ounce loading.

These systems are much like the 1976 system with the major changes being the use of BP EGR, the use higher catalyst loadings, and system recalibrations. The EPA analysis of the GM cost estimates (GM did not provide cost estimates to EPA at either the 1977 Federal or California emission levels) indicates that there could be a maximum initial cost increase to the consumer of about $8.50 over the 1975 systems if no cost saving measures are taken. This maximum figure includes $4 for the BP EGR and $4.50 for the increased noble metal loading. Recent GM testimony to the California Air Resources Board suggests that cost saving measures will be taken and that initial cost to the consumer will not increase. Generally, there should be little change in maintenance costs, though GM failed to comment on this. GM did estimate that there

Table GM-1
1977 Federal Emission Control

Division	Family	CID	EFE	EGR	AIR	Spark Advance	Main Catalyst
Buick	740E2	231	X	BP		M-V	260**
Buick	740E2U	231	X	BP		M-V	260**
Buick	740J2	350	X	BP		M-V	260**
Buick	740J2U	350	X	BP		M-V	260**
Buick	740J4	350	X	P		M-V	260**
Buick	740J4U	350	X	BP		M-V	260**
Cadillac	760J0	350 FI		BP	1.02	M-V	260**
Cadillac	760V4U	425	X	P		M-V	260**
Chevrolet	710C1	140		P	R	M-V	160
Chevrolet	710C1U	140		P	R	M-V	160
Chevrolet	710C2	140		P	R	M-V	160
Chevrolet	710C2T	140		P	R	M-V	160
Chevrolet	710C2U	140		P	R	M-V	160
Chevrolet	710C2W*	140		P	R	M-V	160
Chevrolet	710F1	250	X	P		M-V	260**
Chevrolet	710F1U	250	X	P		M-V	260**
Chevrolet	710F1Y	250	X	P		M-V	260
Chevrolet	710G2	262/305	X	P		M-V	260**
Chevrolet	710G2U	262/305	X	P		M-V	260**
Chevrolet	710J4	350	X	P		M-V	260**
Chevrolet	710W1	1.4ℓ/1.6ℓ		P		M-V	160
Oldsmobile	730H2	260		BP		M-V	260**
Oldsmobile	730H2U	260		BP			260**
Oldsmobile	730M4	350/403		BP		M-V,E	260**
Oldsmobile	730M4U	350/403		BP		M-V,E	260**
Pontiac	720K4	350/400	X	P		M-V	260**
Pontiac	72052U	302		P		M-V	260**
Pontiac	720X2U	151	X	P		M-V	160

* Catalyst change vehicle

** .08 troy oz.

R = reed valve

Table GM-2
1977 California Emission Control Systems

Division	Family	CID	EFE	EGR	AIR	Spark Advance	Main Catalyst	Start Catalyst
Buick	740E25U	231	X	BP	X	M-V	260**	
Cadillac	760JOU	350^{FI}		BP	1.02	M-V	260**	
Cadillac	760VOU	425^{FI}		BP	1.2	M-V	260**	
Cadillac	760V4UW*	425	X	BP	1.2	M-V	260**	
Chevrolet	710C2WZ*	140		P	R	M-V	260**	
Chevrolet	710F1C	250	X	P	1.15	M-V	260**	
Chevrolet	710F1SWMU*	250	X	P	1.15	M-V	260**	60
Chevrolet	710F1SWU*	250	X	P	1.15	M-V	260**	
Chevrolet	710G2LW*	262/305	X	P	X	M-V	260**	
Chevrolet	710G2VW*	262/305	X	P	X	M-V	260**	
Chevrolet	710J4KW*	350	X	P	1.32	M-V	260**	
Chevrolet	710J4SW*	350	X	P	1.32	M-V	260**	
Chevrolet	710W1P	1.6ℓ		P	R	M-V	160	
Chevrolet	710W1PU	1.6ℓ		P	R	M-V	160	
Chevrolet	710W1PW*	1.6ℓ		P	R	M-V	160	
Chevrolet	710W1V	1.4ℓ/1.6ℓ		P	0.88	M-V	160	
Chevrolet	711B0	122^{FI}			R	M	260**	
Oldsmobile	730M4AUW*	350/403		BP	1.25	M-V,E	260**	
Oldsmobile	730M4UW*	350/403		BP		M-V,E	260**	

* Catalyst change vehicle

** .08 troy oz.

R = reed valve

would be a 5% reduction in fuel economy compared to what could be accomplished in 1977 if the NOx level were 3.1. According to GM, only about half of that fuel penalty will result when compared to 1976 models. The EPA analysis of the changes in fuel economy of GM prototype and certification durability vehicles is presented in table GM-3. A preliminary EPA analysis of the 1977 GM certification vehicles at high mileage indicates fuel economy losses for only the lightest vehicles, when compared to their 1976 counterparts. The heavier vehicles generally showed improved fuel economy. Consideration of the weight reductions planned by GM should yield an overall fuel economy improvement for GM in 1977.

As indicated in table GM-2, the 1977 GM systems for California will generally be similar to the Federal vehicles with the addition of either the conventional AIR system or the reed valve (R) AIR system. A start catalyst will be used on one of three Chevrolet families for California with 250 cubic inch engines.

Based on the recent GM testimony and the GM cost estimates at .41 HC, 3.4 CO, 2.0 NOx (not .41 HC, 9.0 CO, 1.5 NOx), we determined that the initial cost increase to be from $33 to $129 compared to 1975 Federal models if cost saving measures are taken. The $33 represents the addition of AIR, BP EGR, an electric choke, and a catalyst change reminder system, and the higher catalyst loading. The $129 includes the items plus a start catalyst system. These are basically the systems which will be used in California. The average initial cost increase should be near the $33 figure as only one start catalyst family is present in the 19 California families. Compared to the cost of 1976 model California vehicles, no initial cost increase will occur. GM estimated that maintenance costs could increase by $60-70 if catalyst changes are needed during the 50,000 mile durability. GM apparently will try to certify without catalyst change and use the catalyst change option only if necessary. The estimate of about $100 for a start catalyst system may be rather pessimistic. It is estimated that a 60 CID start

Table GM-3
Urban Fuel Economy Comparisons of GM Durability Vehicles

				'76 Federal Durability Vehicle			'76 California Durability Vehicle			Prototype Vehicle					
Mfr.	Eng.	Trans	IW	VIN	5K MPG$_u$	Range MPG$_u$	VIN	5K MPG$_u$	Range MPG$_u$	VIN	Target Standard	5K MPG$_u$	% Change from Fed	% Change from Cal	Range
Cadillac	350-FI	A3	4500	604	12.8	12.8-14.7	604	12.8	12.8-14.7	PF	.41, 9, 1.5	12.2	-4.7	-4.7	12.0-13.2
Chevrolet	140-2	A3	3000	102	21.5	17.2-21.7	118	18.1	16.4-18.6	PF	.41, 9, 1.5	18.3	-14.9	+1.1	16.5-18.3
										64375	.41, 3.4, .4	17.7	-17.7	-2.2	17.1-18.1
										PF	.41, 9, 1.5	17.3	-19.5	-4.4	16.2-18.5
	250-1	A3	4000	142	14.8	14.7-16.7	143	15.3	11.9-16.6	PF	.41, 9, 1.5	14.2	-4.0	-7.2	14.2-15.2
										PF	.41, 9, 1.5	12.0	-18.9	-21.6	12.0-14.6
										77102'	.41, 3.4, 2.0	14.9	+0.6	-2.6	14.8-16.6
										77104'	.41, 3.4, 2.0	14.6	-1.4	-4.5	14.6-16.6
	350-2	A3	4500	132	12.7	11.9-13.9				77101	.41, 3.4, 2.0	10.5	-17.3		10.5-12.4
										77103	.41, 3.4, 2.0	9.6	-24.4		8.9-11.4
	350-4	A3	4500	136	12.2	11.6-12.8	136	12.2	11.6-12.8	65383	.41, 3.4, 2.0	12.6	+3.2	+3.2	12.1-12.9
										PF'	.41, 9, 1.5	12.9	+5.7	+5.7	12.9-13.4
										77111	.41, 3.4, 2.0	12.1	-0.8	-0.8	12.1-13.4
Oldsmobile	260-2	A3	4000	319	13.6	12.9-13.8	319	13.6	12.9-13.8	77304'	.41, 3.4, 2.0	12.3	-9.6	-9.6	11.5-13.2
										77305	.41, 3.4, 2.0	12.9	-5.1	-5.1	12.3-13.8
	350-4	A3	4500	303	14.4	12.7-14.4	305	13.1	12.5-13.1	77307	.41, 3.4, 2.0	11.3	-21.5		11.3-12.5
										77308	.41, 3.4, 2.0	11.5	-20.1		11.5-12.6
										77309	.41, 3.4, 2.0	11.0	-23.6		10.8-12.2
Pontiac	400-4	A3	4500	202	11.8	11.6-12.6	218	10.8	10.5-11.8	77202'	.41, 3.4, 2.0	11.1	-5.9	+2.8	10.9-13.1

PF = Practice Fleet

catalyst should cost about $50 or less. GM estimated that the fuel economy penalty of the California models would be 20-30% compared to what could be accomplished in 1977 at 1.5 HC, 15. CO, 3.1 NOx. This estimate included an additional fuel penalty to meet California end-of-line requirements. This fuel penalty has also been revised by GM to be a 7-8% loss compared to 1976 California to reflect the non-methane hydrocarbon standard. Including weight reductions, this will represent about a 3% overall improvement in fuel economy over 1976 California models, according to GM. The EPA analysis of eleven high mileage durability vehicles for California in 1977 reveals an 8% loss for only one vehicle compared to its 1976 counterpart. The average fuel economies of the eleven vehicles analyzed were comparable (+0.4%) to the 1976 California models. Only vehicles of the same inertia weight in 1977 and 1976 were compared.

Systems to be Used - 1978 Model Year and Beyond

The GM systems for .41 HC, 3.4 CO, 2.0 NOx apparently would be very similar to those discussed for the 1977 California emission levels with possibly more dependence upon start catalysts. Another potential system under consideration is lean burn plus thermal reactors (TR) plus oxidation catalysts (OC). GM feels that this system may offer fuel economy advantages over more conventional systems. This advantage may become negligible if exhaust heat conservation techniques are applied to conventional systems.

The cost estimates in the previous section are also applicable here. GM estimates that there would be a 15-20% loss in fuel economy in 1982 at these emission levels assuming current technology. EPA estimates that with improved technology (switched out start catlaysts added to current systems or closed loop 3-way catalyst systems) there would be no fuel economy penalty, or even a gain, when compared to 1976 models.

The developmental GM systems which have been targeted toward .41 HC, 3.4 CO, .4 NOx include dual catalyst systems, 3-way catalyst systems, and 3-way plus oxidation catalyst systems. Two of three 3-way catalyst vehicles, which were reported, had closed loop electronic fuel injection (EFI). The third vehicle had closed loop carburetion. The carbureted vehicle (65344) is a 350 Nova with EFE, BP EGR, and a pelleted, Engelhard catalyst. Emissions of .35 HC, 4.2 CO, .31 NOx were reported at zero miles. The other two 3-way catalyst vehicles will be discussed in the durability section.

One 3-way plus oxidation catalyst vehicle was reported. It was a 305 Nova with BP EGR, switching AIR, closed loop carburetion, an unidentified 3-way catalyst, and a production 260 oxidation catalyst. The results of two low mileage tests were reported to be .55 HC, 3.6 CO, .37 NOx and .26 HC, 1.16 CO, .43 NOx.

No emission results were reported for two of four dual catalyst vehicles. One of these vehicles will use closed loop carburetion and Gould reduction catalysts. A closed loop carburetor is being used to assist in reducing ammonia formation in the Gould converter. The second vehicle will be like the 3-way plus oxidation catalyst vehicle except that it has a 350 engine and will use a Gulf monolithic reduction catalyst. Engine dyno testing has shown the Gulf catalyst to have about 92% net NOx conversion efficiency at 1,000 dynamometer test hours, which simulated a 50,000 mile durability test but GM indicates that its loading of .032 troy ounces of ruthenium may be too high to be practical for production. The other two dual catalyst vehicles will be discussed in the durability section.

Though no Questor vehicles have been tested recently at GM, GM indicated that they were entering into a joint design and development program with Questor.

GM estimated the initial cost of 3-way catalyst systems to be $147 more than the 1975 system. Most of this $147 is for the closed loop fuel metering system. The dual catalyst system would cost about $337 more than the 1975 system, according to GM. Most of this cost is for closed loop fuel metering and the reduction catalyst. Neither cost estimate includes costs for catalyst change should they be necessary. GM estimated that a 5 to 30% fuel economy loss would be incurred in 1978 compared to what could be obtained at 1.5 HC, 15 CO, 3.1 NOx levels.

GM has not specifically developed vehicles for .41 HC, 3.4 CO, 1.0 NOx, but they indicated that the emission control systems and costs would be like those at .41 HC, 3.4 CO, .4 NOx. In a recent submission to the U.S. Department of Transportation, GM indicated that lean burn vehicles equipped with EGR, thermal reactors, and oxidation catalysts may also have the potential to certify at the .41 HC, 3.4 CO, 1.0 NOx levels. The GM estimate of the capability to achieve these levels is based on relatively large engines in relatively small cars (i.e., a 350 or 400 CID engine in a 3500 lb. car). This submission was quite important as it indicates that the lower level of NOx capability with homogeneous (not stratified charge) lean burn systems may be considerably lower than indicated by other industry sources.

Other Systems

There has been serious consideration given to lean burn systems at GM for various emission levels. At the 1977 California levels, EGR and oxidation catalysts would be required, and it may be desirable to add a thermal reactor for fuel economy considerations. Table GM-4 shows some of the GM efforts. The vehicles with CCS operate lean (about 16:1 A/F) though not as lean as the other vehicles. Vehicles ES 65357 and ES 65383 are particularly impressive. Both data points for ES 65383 with high CO are either the result of a malfunction or are of questionable accuracy, according to GM.

The GM work with start catalysts was disappointing as no switched out start catalyst data or super EFE plus start catalyst data was obtained as yet. GM did note that start catalysts which were not switched out could provide advantages in passing end-of-line audit requirements. EPA concludes that by switching out the start catalyst, similar emissions

Table GM-4
Lean Burn Vehicles

VIN	Model	CID	Control System	Miles	HC	CO	NOx	MPG_u	MPG_H
E594313/ 77602	Chevelle	400	LB	5,000	1.3	7.8	2.0	11.9	
				25,000	1.6	7.6	2.1	12.3	18.5
E565337	Chevelle	350	LB/TR/EFE	4,000	.95	6.0	1.4	12.3	16.8
E565366	Chevelle	350	LB/TR/EFE	4,000	.79	4.4	1.5	12.6	17.4
E565353	Chevelle	350	LB/EFE/OC	5,000	.48	0.7	1.4	13.4	19.0
E594332	Chevelle	400	LB/OC	2,000	.20	1.0	1.5	11.5	
E564379	Chevelle	400	CCS/EFE/EGR/AIR/OC	2,000	.13	1.0	1.5	10.9	
65314	Chevelle	350	LB/EFE/EGR/TR	low	.77	8.8	1.74	12.1	
				low	.65	11.3	1.60	12.4	
				low	.63	5.6	1.6	11.3	
				low	.62	4.9	1.5	11.5	
E565357	Chevelle*	350	LB/EFE/EGR/TR/OC	4,000	.17	1.2	1.0	12.7	17.3
E565383	Monte Carlo	350	LB/EFE/EGR/TR/OC	0	.20	1.35	1.49	12.0	
				5,000	.19	1.60	1.36	12.6	18.8
				10,000	.24	3.2	1.50	12.4	
				15,000	.25	2.1	1.6	12.6	
				20,000	.30	4.5	1.4	12.1	
				25,000	.22	1.2	1.2	12.9	
E565382	Monte Carlo	350	LB/EFE/EGR/TR/OC	0	.20	1.18	1.47	12.2	
				5,000	.18	.99	1.33	12.1	
				10,000	.22	1.7	1.20	12.3	
				15,000	.29	1.7	1.6	12.5	
E565328	Monte Carlo	350	LB/EFE/EGR/TR/OC	0	.14	.95	1.66	11.0	
				5,000	.10	1.30	1.4	11.5	
				10,000	.15	2.06	1.33	11.7	
65305	Vega	140	CCS/EGR/TR/OC	500	.31	4.8	1.7	17.5	23.4

* CCS, current calibration.

benefits can be seen over the entire 50,000 miles of durability without the large increases in HC and CO deterioration factors associated with start catalyst systems that are not switched out. Catalyst descriptions were not provided for prototype main catalysts, thus the GM progress in developing the pelleted oxidation catalysts could not be evaluated.

Alternate Engines

The GM light duty Diesel, scheduled for introduction in 1977 or 1978, is a 350 CID, 4-stroke model developed by Oldsmobile. The emission and fuel economy results in Table GM-5 were reported for this engine.

Table GM-5

The Oldsmobile Diesel
4500 lbs. Inertia Weight

Emissions (gm/mi)				Fuel Economy (mi/gal.)		
Vehicle	HC	CO	NOx	EPA (urb.)	EPA (hwy.)	55/45
52532	0.7	4.1	1.6	18.9	21.4	20.0
	1.6	2.8	1.6	19.6	24.7	21.6
	1.4	2.1	1.8	20.4	28.2	23.3
	0.6	1.8	4.3	18.8	25.2	21.2
52364	1.3	2.3	2.0	18.3	24.5	20.7
	0.5	1.1	2.3	19.1	24.5	21.2
52535	0.3	1.1	3.7	16.9	21.5	18.7
	0.2	1.3	3.0	20.4	25.2	22.3
	0.2	1.2	3.3	18.8	23.7	20.7

The results in Table GM-6 were reported for a 350 CID jet ignition stratified charge (SC) vehicle. Data from a conventional lean burn vehicle was also presented for comparison. Apparently this CVCC-type vehicle was not tested with both the thermal reactors and oxidation catalyst. Based on this vehicle and another series of testing with Honda vehicles GM has concluded that:

Table GM-6
The Jet Ignition Stratified Charge Vehicle
(4500 lb. IW)

System	HC	CO	NOx	MPG_U	A/F
SC+OC	.25	.55	1.50	12.2	19:1
SC+TR	.35	3.38	1.35	10.0	19:1
LB+OC	.27	.94	1.57	12.8	19:1

- "Some conventional homogeneous charge chamber designs are better than others.
- Some stratified charge designs are better than others.
- Stratifying poor conventional combustion chambers improves their performance to near that of the best conventional designs.
- Stratifying good combustion chambers does not significantly improve their performance.
- Running a good stratified charge design with a homogeneous mixture gives essentially the same performance. This points toward the importance of chamber design rather than stratification as the dominant factor."

Thus it does not appear that GM will do further work with this concept. It should be noted that the GM conclusions were drawn from studies at NOx levels between 1.3 and 2.0. These conclusions may be considerably different at the 1.0 or 0.4 NOx levels for which the CVCC could potentially be calibrated, using EGR.

The Texaco Controlled Combustion System (TCCS) Cricket was tested with mixtures of gasoline and Diesel fuel. GM concluded that its fuel economy was no better than a conventional engine and that HC emissions were unacceptably high. The FTP results were 1.3 HC, .77 CO, 2.1 NOx and 25 mpg with a 50/50 blend of gasoline and Diesel fuel.

The GM turbine work is being directed toward fuel economy improvements. The best fuel economies reported were 8.7 for the FTP and 16.0 for the highway test in a 4500 pound inertia weight vehicle. No emission results were reported.

The conventional rotary engine was reported to now have engine-out HC emissions reduced to about 4-8 gm/mi. But until further reductions of HC and improvements in fuel economy are achieved, the rotary apparently will not be considered for production by GM. Developmental efforts were reported on both stratified charge and Diesel rotaries, but no emission data was reported for either concept.

Durability Testing Program - 1977 Model Year

The California Division of Highways Fleet has continued to operate twenty-five Oldsmobiles with EGR, EFE, and oxidation catalysts which were targeted toward .41 HC, 3.4 CO, 2.0 NOx. Thirteen of the vehicles have no AIR and twelve have AIR. Three no AIR vehicles have now completed 50,000 miles and the remaining ten have accumulated at least 39,000 miles. All of the AIR vehicles were reported to be between 31,000 and 36,000 miles. The GM analysis of the twenty-five 455 CID vehicles is found in Tables GM-7 and GM-8.

Table GM-7
California Division of Highways Fleet

Oldsmobiles Without Air Pumps (5000 lb. IW)

		HC	CO	NOx
Projected Emissions at 50,000 miles (g/mi)	Avg.	0.33	4.97	1.93
	Range	0.21-0.66	3.54-7.43	1.70-2.44
Deterioration Factor	Avg.	1.63	2.77	1.04
	Range	1.00-2.36	1.30-7.87	1.00-1.25
Percent of vehicles meeting individual constituent targets of 0.41 HC, 3.4 CO and 2.0 NOx		85%	0%	61%
Percent of vehicles meeting combined targets of 0.41 HC, 3.4 CO and 2.0 NOx		---	0%	---

Table GM-8
California Division of Highways Fleet

Oldsmobiles With Air Pumps (5000 lb. IW)

		HC	CO	NOx
Projected Emissions at 50,000 miles (g/mi)	Avg.	0.43	2.58	1.74
	Range	0.17-0.93	0.79-7.03	1.51-2.17
Deterioration Factor	Avg.	1.52	2.96	1.03
	Range	1.00-4.89	1.00-8.57	1.00-1.38
Percent of vehicles meeting individual constituent targets of 0.41 HC, 3.4 CO and 2.0 NOx		58%	83%	92%
Percent of vehicles meeting combined targets of 0.41 HC, 3.4 CO and 2.0 NOx		---	42%	---

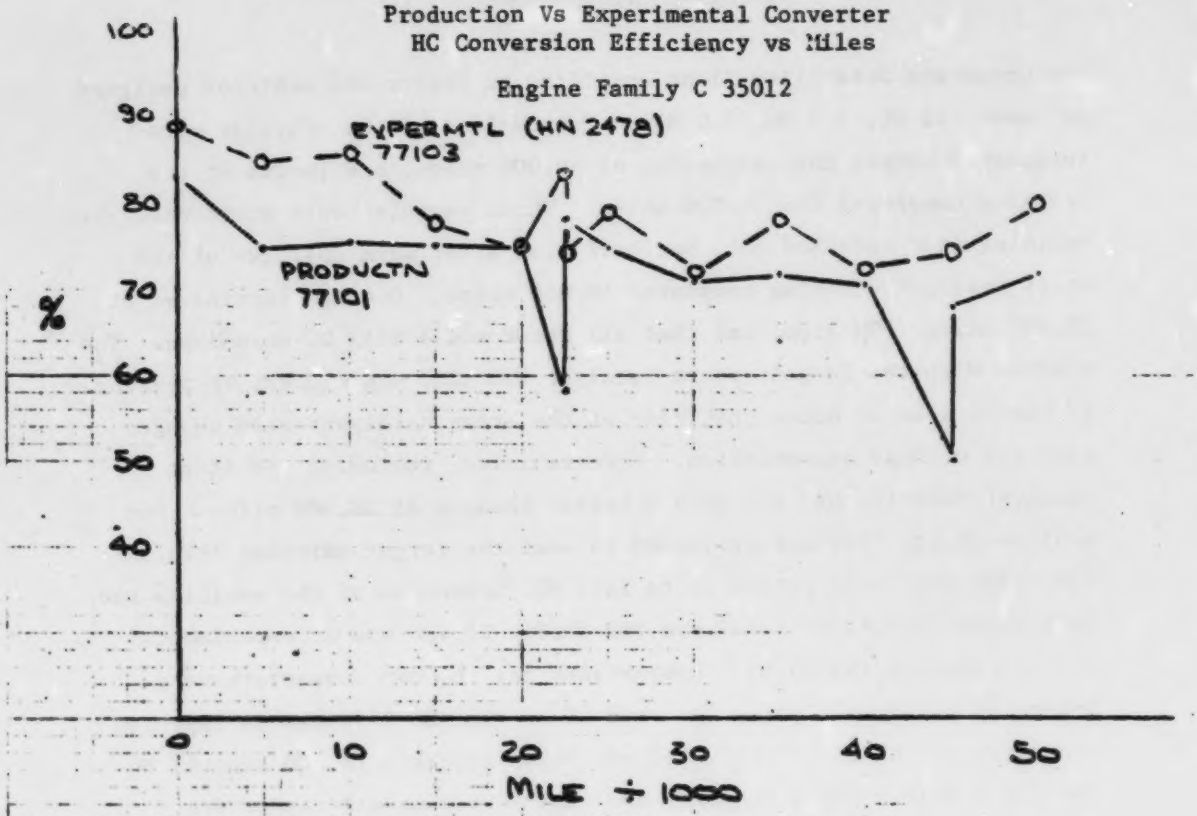
The Corporate Durability Fleet consisted of thirty-six vehicles designed to meet .41 HC, 3.4 CO, 2.0 NOx. Twenty-four of the vehicles were terminated before the completion of 50,000 miles, and twelve of the vehicles completed the 50,000 miles. Three vehicles were start catalyst vehicles (not switched out, but half flow after warm up). Two of the start catalyst vehicles completed 50,000 miles. One was terminated at 35,000 miles. GM predicted that all three would fail HC emissions. The vehicle with the largest start catalyst (60 CID) was closest to passing. It should also be noted that none of the start catalysts were changed over the mileage accumulation. Five vehicles, including one start catalyst vehicle, had the main catalyst changes at 30,000 miles. One vehicle of the five was projected to meet the target emission levels. The other four were projected to fail HC. Seventeen of the vehicles had 1976 production Pt/Pd catalysts (HN-2300). Eleven had an experimental all Pt catalyst (HN-2478). Comparisons for the two converters were presented by GM in figures GM-1 and GM-2. The HN-2478 was an improved converter on the 350 family, but was less favorable for CO control on the 250 family. Three vehicles had other experimental converters. Vehicle 77207 was particularly impressive until 22,500 miles. After that scheduled maintenance point, the engine out emissions, tailpipe emissions, and fuel economy changed significantly. Neither the reasons for these changes nor the reasons for removing the vehicle from the corporate durability fleet were explained by GM.

The GM analysis of the Corporate Durability Fleet is found in Table GM-9. Some vehicles were not considered in this analysis because of evaporative interaction problems.

The remaining five vehicles in the Corporate Durability Fleet included two 3-way catalyst cars, one lean burn plus oxidation catalyst car, one lean burn only vehicle, and one stratified charge plus oxidation catalyst vehicle. Both 3-way vehicles were terminated within 5000 miles. One was failing HC and CO and the other had a mechanical problem with the

Figure GM-1
Experimental Converter
Production Vs Experimental Converter
HC Conversion Efficiency vs Miles

Engine Family C 35012



CO Conversion Efficiency vs Miles

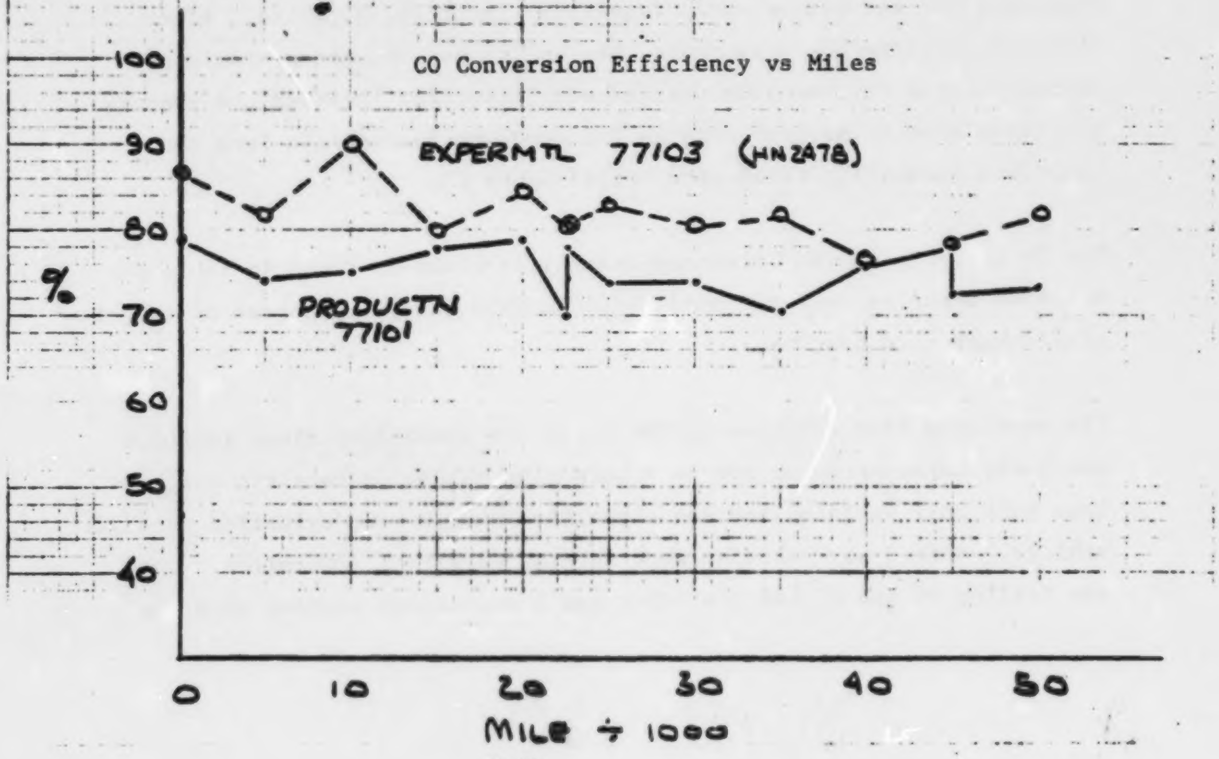
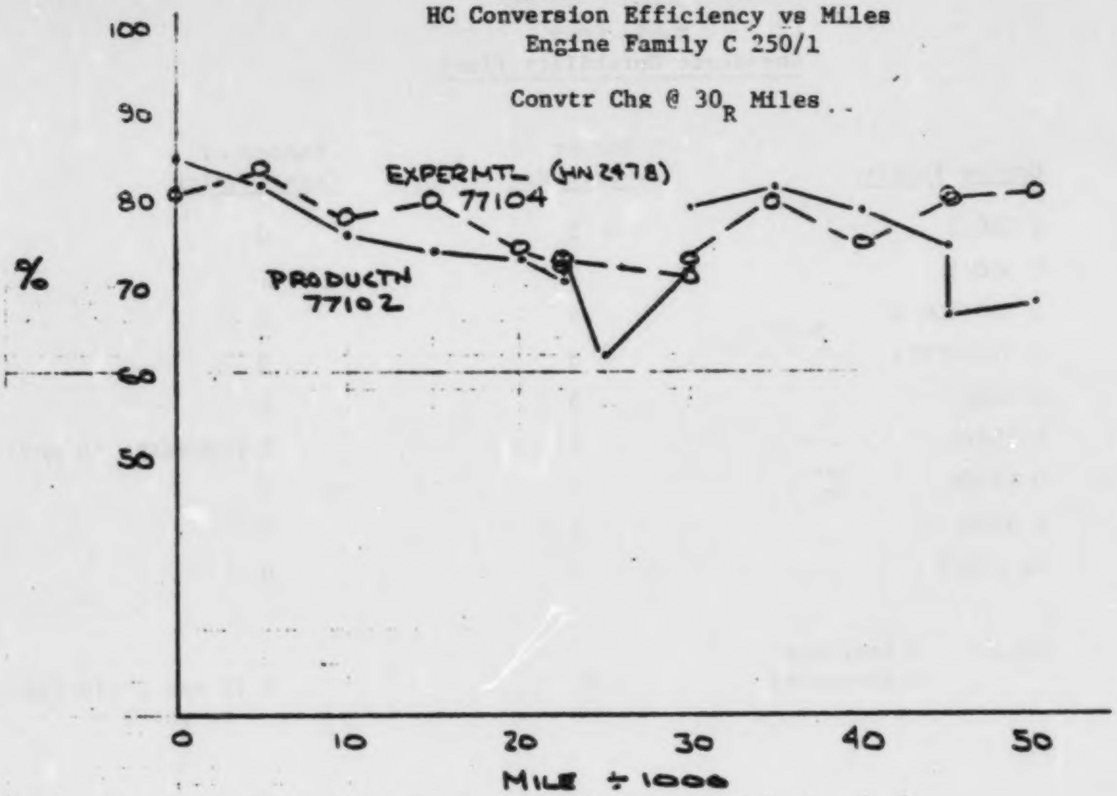


Figure GM-2
Experimental Converter
HC Conversion Efficiency vs Miles
Engine Family C 250/1

Convtr Chg @ 30_R Miles



CO Conversion Efficiency vs Miles

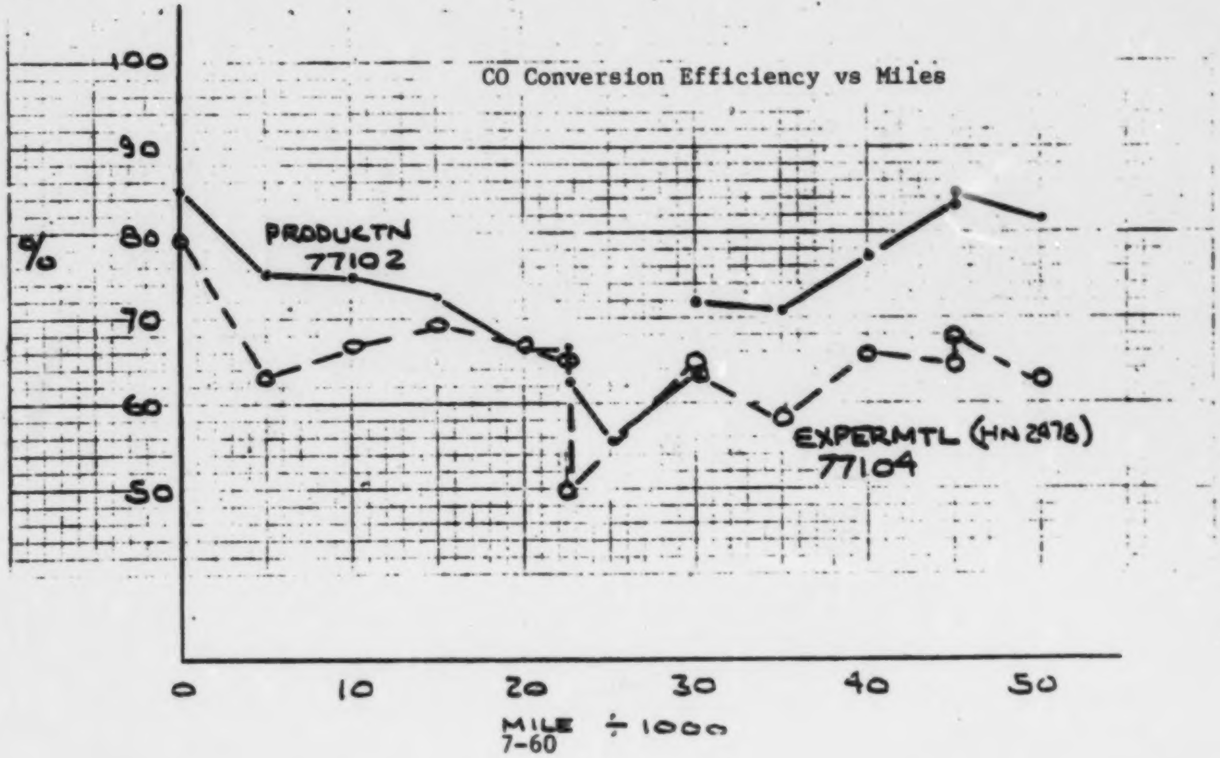


Table GM-9
Corporate Durability Fleet

Engine Family	Number of Cars Run	Number of Cars Passing
C 250/1	2	0
C 350/2	2	1
C 350/400/4	4	0
P 350/400/4	5	0
O 260/2	3	1
O 350/4	4	1 projected to pass
O 403/4	1	0
B 350/2	2	0
Ca 425/4	1	0
Totals: 8 Families Represented	24	3 (1 was projected to pass)

engine. The lean burn plus oxidation catalyst vehicle was failing HC and was terminated at 30,000 miles. The lean burn only vehicle was terminated at 25,000 miles. This was vehicle 77602 in Table GM-4. The stratified charge vehicle remained within the program targets until 38,000 miles. At this point a prechamber valve failed and the vehicle was terminated. Some of the durability results for this vehicle are presented in Table GM-10.

Table GM-10
Durability Results of the Jet Ignition
Stratified Charge Plus Oxidation Catalyst Vehicle
(350 CID, 4500 lb. IW)

Mileage	HC	CO	NOx	MPG$_U$	MPG$_H$
0	.14	.40	1.34	10.76	--
5,000	.23	.55	1.62	10.87	15.16
10,000	.22	.32	1.67	10.69	
15,000	.21	.38	1.59	10.97	
20,000	.28	.37	1.63	10.57	
25,000	.34	.49	1.38	10.71	15.43
30,000	.36	.87	1.97	10.86	15.89
35,000	.27	1.06	1.77	10.32	15.42

Another fleet called the Practice Durability Fleet is now running at the 1977 Federal and California levels. HC emissions appear to be improved on this fleet, but still higher than GM may desire. The CO emissions from vehicles targeted for the 9 CO level seem to provide a very favorable CO cushion for certification. The catalyst change vehicles also are showing reduced deterioration for HC. One vehicle has an HC DF of about one.

Durability Testing Programs - 1978 Model Year

The level of effort currently being expended on durability testing of 1978 systems for .41 HC, 3.4 CO, .4 NOx indicate that GM will not be able to certify vehicles in 1978 at those emission levels. GM maintains that emission control systems for achieving those levels are still not developed. There are two 3-way catalyst vehicles which have accumulated mileage. Both are 140 CID Vegas at 3000 lb. IW with BP EGR, closed loop electronic fuel injection, and underfloor catalysts. Vehicle 64384 is using an Engelhard, monolithic catalyst, and vehicle 65375 is using a pelleted DeGussa catalyst. Their emission results to date are reported in Table GM-11. Vehicle 65375 showed some of the best durability results with a 3-way catalyst

Table GM-11

3-Way Catalyst Durability Testing

Vehicle	Mileage	HC	CO	NOx	MPG_U	MPG_H
64384	0	.26	1.69	.16	17.3	23.5
	0	.24	2.54	.29	20.2	
	5,000	.22	1.82	.43	21.0	
	5,000	.21	2.14	.71	21.7	
	10,000	.21	2.19	.76	21.6	
	10,000*	.29	4.60	.41	21.1	
65375	0	.18	2.42	.21	16.9	
	0	.19	2.36	.36	17.6	
	5,000	.26	3.81	.39	17.7	
	10,000**	.17	2.35	.37	17.1	
	15,000	.20	3.49	.38	18.1	
	15,000***	.18	3.18	.27	17.9	
	20,000	.22	2.82	.32	17.7	

* richer A/F ratio

** EGR valve replaced

*** Oxygen sensor replaced

vehicle that has been reported to EPA. The achievement of the statutory emission levels at 20,000 miles with a 3-way catalyst vehicle is considered an important technological accomplishment. The reasons for differences in fuel economy between the two vehicles was not explained by GM. There is essentially no fuel economy penalty for 64384, though both vehicles had compression ratios of 9:1 and probably would not operate on 91 RON fuel. If the compression ratio were lowered, HC and NOx would probably be lowered. Mileage accumulation is continuing on both vehicles.

Two dual catalyst vehicles have been tested. Both are 350 CID vehicles at 4500 lb. IW with BP EGR, EFE, switched AIR, and production oxidation catalysts. Vehicle 65336 uses the Gould reduction catalyst with an oxygen getter, and vehicle 6330X uses a TDK, pelleted reduction catalyst. Their test results are shown in Table GM-12.

Table GM-12

Dual Catalyst Durability Results

Vehicle	Mileage	HC	CO	NOx	MPG_U	MPG_H
65336	0	.33	1.3	.27	9.9	
	5,000	.42	3.3	.47	10.5	
	10,000	.48	3.3	.38	10.4	
	12,000	.58	4.3	.56	9.9	
	-	.43	1.6	.38	10.2	
	15,000	.53	3.2	.47	10.3	
	15,000	.52	3.7	.46	10.6	
6330X	0	.29	2.8	.33	10.0	
	5,000	.33	4.4	.50	10.7	
	10,000	.35	5.4	.85	10.7	
	-	.35	6.5	.54	10.6	

No durability testing was reported at the .41 HC, 3.4 CO, 1.0 NOx levels.

7.1.4.3 Progress and Problem Areas

Progress and Problems - 1977 Model Year

If early certification results are representative, GM will do a considerable amount of HC and NOx "line crossing" in California. The HC problem suggests that GM is either having fuel metering problems or catalyst problems. The catalyst problem may be the relatively slow light off of the GM converters. Their non-switched out start catalysts may not help as they will reduce low mileage HC emissions, but could increase the DF. GM reported that the catalyst change option had not provided the expected DF benefits on the Corporate Durability Fleet, but catalyst change results on the more recent Practice Durability Fleet reflect the expected improvements. The catalyst change option may be used for some engine families, though others will not now need it because of improved deterioration factors for 1977. The main reason for the improved DF's in table GM-13 is the reduced lead and phosphorus levels in the revised certification fuel for 1979.

Table GM-13

Changes in DF between 1976 and 1977
Durability Vehicles

	Average Change in DF
HC	-0.47
CO	-0.44
NOx	+0.01

GM has made considerable progress on lean burn plus thermal reactor plus oxidation catalyst systems. These systems have initially shown the potential to minimize fuel economy losses projected by GM at the .41 HC, 9 CO, 1.5 NOx levels. Progress on the GM light duty Diesel which may be introduced in 1977 also has been good. HC emissions of the Diesel may be a little high yet, but are expected to improve as more work is done. The vehicle weight reduction program will begin in 1977 with initial changes starting with the heaviest end of the GM model line.

Progress and Problems - 1978 Model Year

A big problem for GM and others in the industry in 1978 is that the emissions standard is still mandated at the statutory levels. Since GM maintains that the required technology does not exist to comply with the statutory levels in 1978, apparently no orders have been placed for the catalysts. Thus GM may be forced into calibration changes of current-type systems for 1978.

According to GM, catalyst durability remains a problem for both 3-way catalyst and dual catalyst systems, and fuel metering may be a problem for the 3-way catalyst systems. This could be a bigger problem for GM than for other manufacturers who are working on fuel metering systems which have feedback capability and are more sophisticated than carburetion, but less sophisticated (and expensive) than fuel injection. Other remaining problems with 3-way catalyst systems, according to GM, are sensor drift, window size, and window drift. However, the completion of 20,000 miles on a 3-way catalyst vehicle at statutory emission levels demonstrates considerable progress.

7.2 Independent Developers

7.2.1 Dresser

Dresser Industries is a multi-divisional company which produces a variety of products including, gas station pumps, tools, safety valves, and oil drilling equipment. Since 1970 Dresser has been involved in the development of a sonic carburetor known as the "Dresserator". Dresser felt the potential for the carburetor system, which was formerly under development at Stanford Research Institute, was sufficient to allow them to eventually obtain licensing fees from the automobile industry for its use.

The Dresser concept is to achieve fine fuel atomization over a wide range of operating conditions by maintaining a choked flow condition in the carburetor throat and metering fuel upstream of the throat so that it must pass through the shock wave that occurs when the flow goes sub-sonic in the diffuser which is located downstream of the throat. The extremely fine droplet sizes reportedly created by the Dresserator (10 micron diameter) allow uniform air/fuel ratios (A/F) to be achieved during warm-up and transient conditions that cause A/F variability problems with conventional carburetors. The wall wetting that occurs with conventional carburetors is less of a problem for the Dresserator. The coarser droplet size and heavier wall wetting that is characteristic of a conventional carburetor results in significant variations in air fuel ratio from cylinder to cylinder and from one cycle to the next cycle (successive intake charges for the same cylinder). To prevent lean misfire in a conventionally carbureted engine, this is counteracted by richening up the overall mixture so that the lean cylinders are not too lean. This has prevented the achievement in practice of the theoretical benefits of lean (18-19:1 A/F) operation.

The achievement of sonic flow in a carburetor is not a new accomplishment. Conventional carburetors experience sonic conditions at idle and extremely light load operation where the ratio of manifold to ambient pressure is less than .528. The Dresser carburetor, however, maintains sonic conditions over most of the engines operating range including modes where intake manifold pressure approaches ambient pressure. This is accomplished by the variable area, converging-diverging geometry of the Dresserator. Figure Dresser-1 is a schematic of the Dresserator geometry. Movement of a slider between two fixed jaws accomplishes the throat area changes necessary as the engines air requirement changes. Previous versions of the Dresserator have employed moveable jaws without a slider and annular geometry with a vertically moveable cone to vary throat area. Figure Dresser-2 is a prototype Dresserator completely assembled.

Emission Performance

Dresser equipped vehicles tested by EPA and others have demonstrated that the level of "untreated" emissions necessary to achieve the 1977 California Standards (.41, 9.0, 1.5) with a catalytic aftertreatment system can be achieved with excellent fuel economy. In order to achieve the 1977 California levels the pre-catalyst emission levels need to be:

HC = .41 ÷ (1-.7) = 1.37
CO = 9.0 ÷ (1-.8) = 45
NOx = 1.5 ÷ (1-0) = 1.5

Levels lower than these have been demonstrated by Dresser on several vehicles. Even without catalysts Dresser test vehicles have approached or equalled the 1977 California standard when some spark retard is used to reduce HC. The use of catalysts will allow Dresser equipped vehicles to simultaneously achieve fuel economy that is superior to the economy achieved by typical vehicles in any previous model years, including uncontrolled. Typical non-catalyst emission levels for Dresser equipped vehicles are shown in Table Dresser-1.

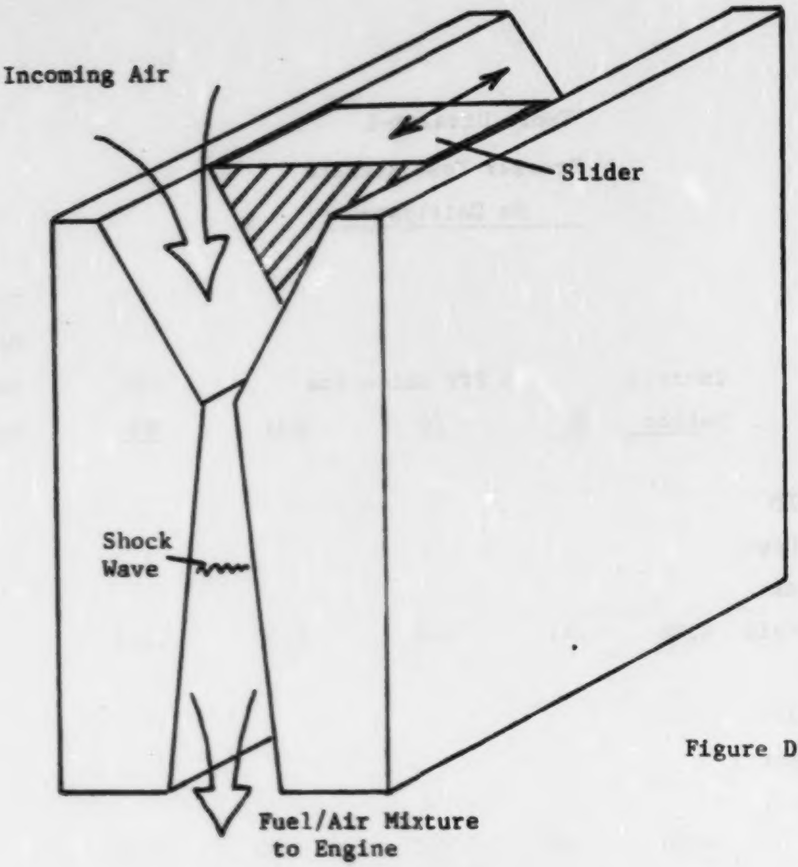

Incoming Air
Slider
Shock Wave
Fuel/Air Mixture to Engine

Figure Dresser-1

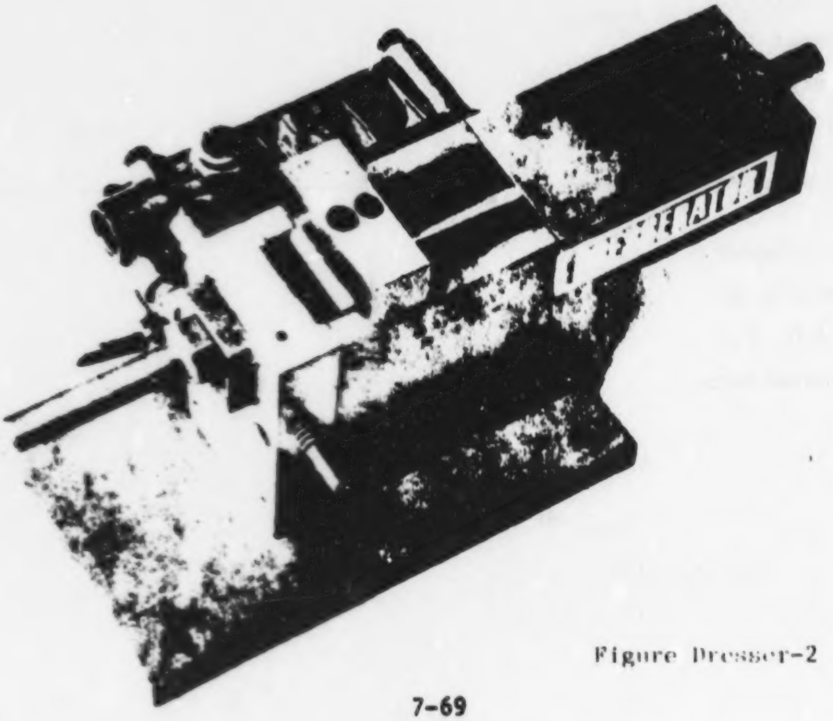


Figure Dresser-2

Table Dresser-1

Dresser Test Results

No Catalysts

Vehicle	Inertia Weight	'75 FTP Emissions HC	CO	NOX	FTP MPG	Typical Uncontrolled Car of Same Weight, MPG
Ford 351 CID w/Dresser Carb and large exhaust manifold	4500	.41	4.7	1.30	11.3	12.2
Chevrolet 350 CID w/Dresser carb and std. manifolds	4500	.88	4.7	1.70	12.9	12.2
Capri 2600 cc w/Dresser Carb and large exhaust manifolds	2750	.77	5.62	1.98	19.9	16.1
Levels needed to certify at .41, 9.0, 1.5 with catalysts		1.37	45	1.5		

Auto Manufacturer's Cooperation

Cooperative studies have been carried out by Dresser with Ford, GM, and Chrysler with Ford showing the most interest. Ford and Holley Carburetor have signed licensing agreements so far. No manufacturer is showing a level of effort that is indicative of a commitment to mass produce the system.

Progress and Problem Areas

Dresser reports that over the past year they have changed their method of fuel metering from a pressure regulated system to more conventional vacuum metering (float) with an air bleed technique for compensation. Dresser Claims that their current Model III unit (fixed jaw with slider) is a "bolt on" unit which can be used to retrofit a standard carburetor. Since one of Dresser's major problems up to this time has been the automobile manufacturers unwillingness to adopt such an unorthodox design with its attendant retooling expense, these changes should enhance the carburetors appeal. Other problem areas with the carburetor have been cold starting,, insufficient power enrichment, and throttle feel. Dresser reported work on these problem areas.

No significant efforts have been made to adapt the Dresser carburetor to non-lean burn approaches such as 3-way catalyst or dual catalyst systems. Its precise air fuel ratio control would be valuable to both of these systems. 3-way catalysts systems might be helped, since the Dresser carburetor might eliminate the requirement for feedback air/fuel ratio control.

Holly Carburetor Division of Colt Industries is a licensee of Dresser. Working under an EPA contract, Holley is outfitting a 1975 Dodge Dart with a modified Model III Dresser carburetor. The Dart which is equipped with the 225 cu. in. six cylinder engine, will also have back pressure EGR, high energy ignition and a catalyst. The goal of the contract is to demonstrate the .41 HC, 3.4 CO, 2.0 NOx level with improved fuel economy over the baseline car. EPA will evaluate the car for a period of time following Holley's preparation and testing of it and may at that time equip the car with a 3-way catalyst or some other promising system for further evaluation.

7.2.2 Ethyl Corporation

Recent news media coverage prompted EPA to solicit the development status of the Ethyl Corporation Turbulent Flow System (TFS). It has been Ethyl's desire to produce an all mechanical emission control system and reduce the dependence on catalytic aftertreatment control for emission reduction. Of course, by not using a catalytic converter the Ethyl Corporation would hope to demonstrate an emission control system not requiring lead-free fuel.

The essential features of the TFS are the long mixing tube below the primary venturi, the change of flow direction in the mixing box, and the secondary venturi bypass. The long mixing tube allows the fuel-air mixture downstream of the throttle to become more uniform. Changing the flow direction increases turbulence which improves the mixture quality and causes large fuel droplets to fall onto the mixing box floor, where they are vaporized before reentering the stream. The secondary flow bypasses the mixing box to minimize pumping losses, thus minimizing losses in volumetric efficiency. The intake manifold (Figures Ethyl-1 and-2) is a Dodge intake manifold. Exhaust port liners were installed in the heads and lean thermal reactor manifolds replaced the original exhaust manifolds.

The significance of the TFS is not in the operation of the engine with lean calibration but in the use of heat conservation and lean reactor techniques. Lean calibration techniques have been used by all major manufacturers as have early fuel evaporation for better fuel mixing and distribution. The use of port liners has been limited to foreign manufacturers who have concentrated on lean reactors. It is felt that the increase in exhaust gas temperatures by use of port liners will aid the control of HC and ease the load on the catalytic converter plus aid in rapid light off of the catalyst. A catalytic converter combined with the TFS could prove to be very effective in meeting future emission levels.

TURBULENT FLOW MANIFOLD

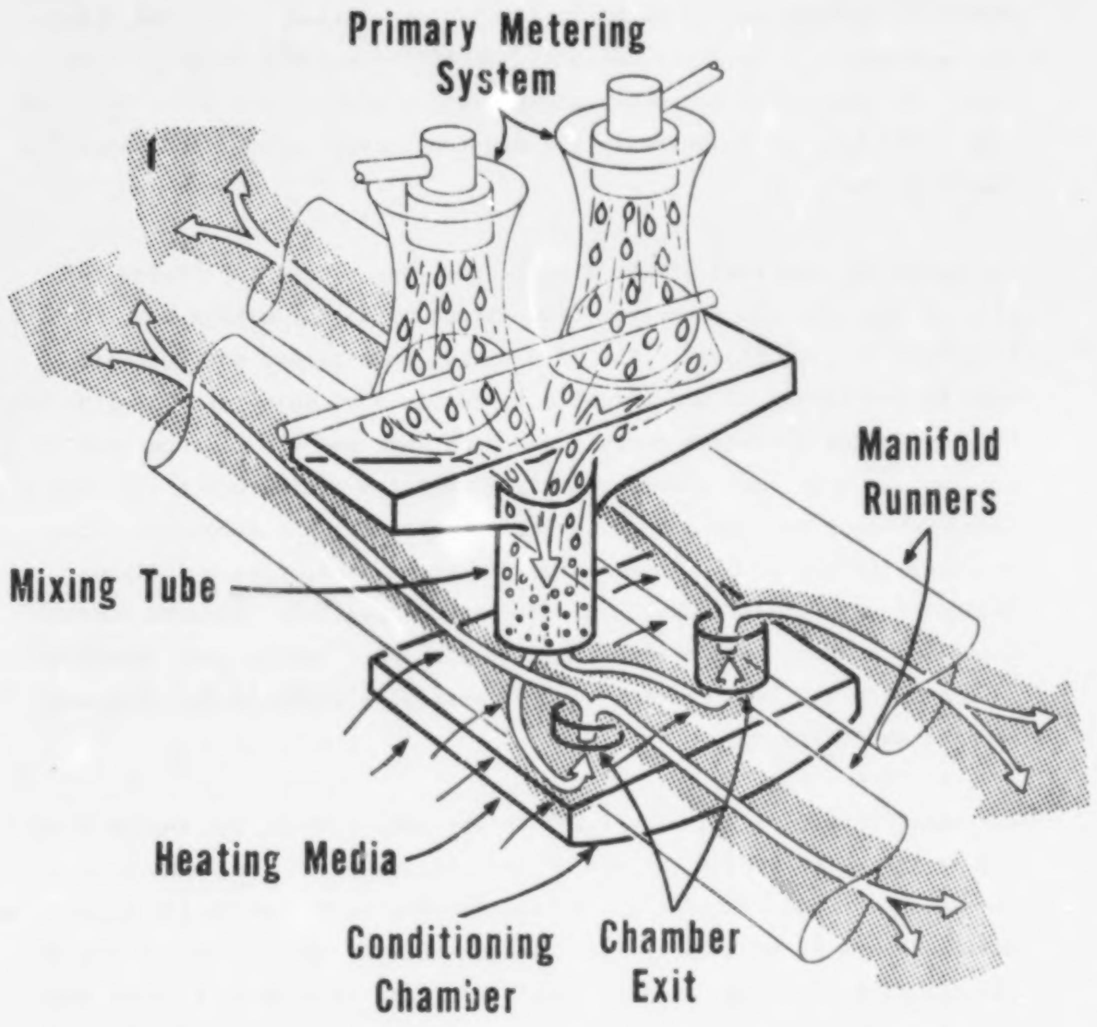
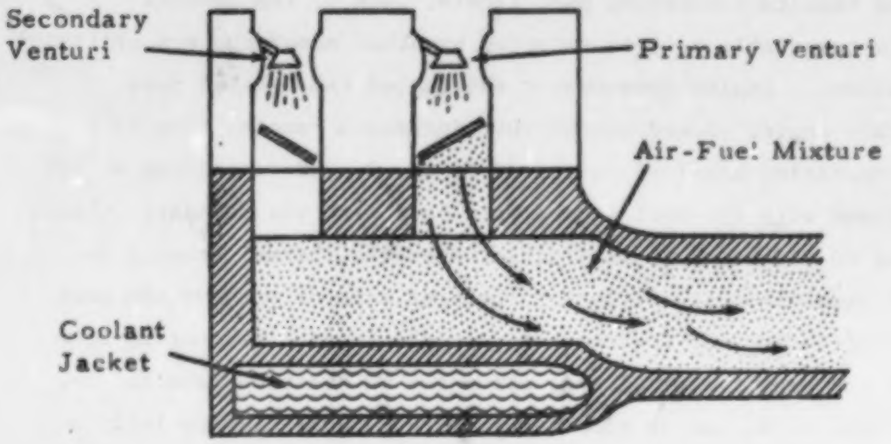
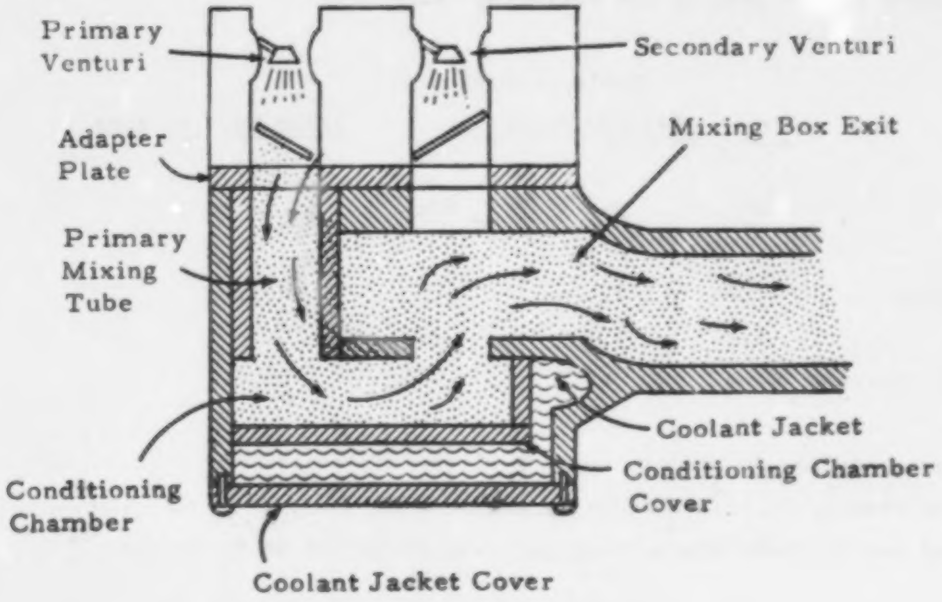

Primary Metering System
Manifold Runners
Mixing Tube
Heating Media
Conditioning Chamber
Chamber Exit

Figure Ethyl-1 Turbulent Flow Manifold


Secondary Venturi
Primary Venturi
Air-Fuel Mixture
Coolant Jacket

Standard Manifold


Primary Venturi
Secondary Venturi
Adapter Plate
Mixing Box Exit
Primary Mixing Tube
Coolant Jacket
Conditioning Chamber Cover
Conditioning Chamber
Coolant Jacket Cover

Turbulent Flow Manifold

Figure Ethyl-2 Comparison of Turbulent Flow Manifold with Standard Intake Manifold

Ethyl in their submission detailed their studies involving the use of port liners, air-fuel ratio optimization, EGR distribution, and the effect of increased compression ratio. With the exception of the comprehensive results concerning port liners, much of the details reported were comparable to data reported by other manufacturers utilizing lean calibrations. Engine dynamometer testing of the exhaust port liners for this engine showed temperature increases ranging from 40°F to 90°F at the operating air-fuel ratios of 16 to 17. HC reductions of 20% to 50% are found with the port liners when used with the standard exhaust manifold, but CO reduction is negligible. When the thermal reactor is used, the HC reductions are virtually the same with or without the port liners. The efficiency of CO conversion in the thermal reactor is more dependent on the use of port liners, since the CO reaction rate is slower than that of HC and is more temperature dependent, especially at the low concentrations entering the reactor. CO reductions with the thermal reactor ranged from 0% to 60% with no port liners. However, reductions ranging from 38% to 86% at an A/F of 17:1 were found when the port liners were installed. The effect of port liners and the TFS on fuel economy can be seen in the following table Ethyl-1.

Table Ethyl-1

	1975 CVS Emissions g/mile			Urban Fuel Economy mpg
	HC	CO	NOx	
As received	1.84	19.06	1.55	9.7
TFS	1.24	7.31	2.03	10.4
TFS+Port Liners	.52	6.79	1.85	10.4

Ethyl has conducted durability testing of the TFS system for over 50,000 miles the results of this durability are seen in Table Ethyl-2. The fuel used during these tests contained 2.2g Pb/gallon as Motor Mix.

Table Ethyl-2

Emission Data

Car #857 - 360-CID V-8
With TFS, Exhaust Port Liners, Reactor Manifold

	'75 CVS gram/mile					
Test Mileage	**HC**	**CO**	**NOx**	**MPG**		
0	0.22	3.33	1.26	10.4		
3,000	0.24	4.29	1.66	10.6		
5,000	0.30	4.61	1.83	11.3		
10,000	0.35	5.05	1.77	11.1		
15,000	0.34	4.93	2.13	10.7		
20,000	0.43	4.66	2.02	11.3		
25,000	0.49	6.33	1.78	11.1		
30,000	0.41	5.77	1.79	11.3		
35,000	0.48	5.70	1.97	11.9		
40,000	0.37	5.06	1.75	11.1		
45,000	0.41	5.95	1.82	11.2		
50,000	0.43	6.07	1.93	11.3		
D.F.	1.28	1.25	1.00			
50,028	.18	2.49	2.59	18.4		Highway Driving Cycle
52,000*	.38	5.43	1.64	12.5		
	Sulfate Procedure Emissions				H_2SO_4**	
52,000*	.36	6.88	1.80	11.8	17.6	FTP
	.06	1.43	2.48	20.1	6.2	Hwy Cycle
	.10	2.89	1.83	17.0	5.9	Sulfate

* EPA Test Report No. 76-6
**Milligrams per mile

The durability vehicle received manufacturer's recommended maintenance at all specified intervals. The failure and wear rates of the emission control hardware were nominal according to Ethyl.

Additionally during the durability testing a dual inlet tangential anchored vortex trap was used to control particulate emissions. Two duty cycles were used, the durability route cycle and a severe-duty route consisting of five W.O.T. accelerations from 20 to 50 mpg and one freeway entry acceleration from 20 to 60 mph. The results of these tests are in Table Ethyl-3.

Table Ethyl-3

Particulate Emissions Comparison

	Durability Route			Severe Duty	
	Miles	Total*	%Pb**	Total	%Pb
Standard Vehicle	32,000	0.088	54.8	0.339	408.3
Car 857	50,000	0.042	13.1	0.164	69.1
% Reduction		59	76	52	

* Includes lead and non-lead particulate, grams per mile data

**% of input fuel lead exhausted

Ethyl reported that work continues on further developing the lead-compatible emission control system. They also reported cooperative efforts with the domestic and foreign automotive companies component companies and with various government agencies. They did not provide any cost data for the system.

While Ethyl's efforts to achieve low emission results with non-catalytic methods have been good, additional efforts could improve the system. Other manufacturers report that up to .10 gram/mile HC reduction can be obtained by removal of lead from the motor fuel. This reduction plus the use of a catalytic converter will allow reoptimization for improved fuel economy and lower NOx levels from increased EGR rates. Similar combinations of lean calibration, thermal reactors, and oxidation catalysts have shown promise in obtaining low emission levels with good fuel economy. However, the driveability of lean calibration vehicles such as the TFS system must be explored. Ethyl provided no details on driveability.

Ethyl has been experimenting with Methylcyclopentadienyl manganese tricarbonyl (MMT) as an antiknock additive since 1957. With the removal of TEL from gasoline, the substitution of low concentrations of MMT (up to 0.125 gm/gallon) has become more economically attractive. Ethyl provided extensive data regarding the effects of MMT on vehicle operation, catalyst durability, emissions performance and other engine related phenomena. A synopsis of these results follows. Use of MMT in typical 91-RON unleaded gasoline at a concentration of 0.125 gm/gallon provides, on the average, about 1.5 to 2.3 road octane numbers increase. There appeared to be no exhaust valve durability problems at either extended or increased severity engine dynamometer or road durability testing with MMT. Ethyl reports no spark plug problems, while other manufacturers report that MMT effects spark plug fouling opposite to the way lead does, i.e. the hotter the plug, the more fouling that occurs. Therefore more attention to spark plug ranges will have to be given by the manufacturers. Ethyl reported reduced engine wear or no more than normal engine wear. MMT effects on both exhaust emissions and catalyst life were indicated by Ethyl as not detrimental. The average emissions over extended durability appear to be no effect on HC, a beneficial effect on CO, and a slightly negative affect on NOx. Refer to Table Ethyl-4. The immediate effect of MMT can be seen in Table Ethyl-5. There appears to be little or no benefit for emission reduction from MMT addition. However, further work is necessary to quantify these results independent of this submission.

Catalyst plugging using MMT was reported by a vehicle manufacturer. Accelerated tests by Ethyl using twice the normal concentration revealed

TABLE Ethyl-4
Fleet Emission Summary
1975 California Cars
Base Fuel: 91-RON Unleaded
MMT: 0.125 g Mn/gallon

Test	Average Emissions, g/mile					
	Base Fuel (8 Cars)			MMT (14 Cars)		
Miles	HC	CO	NO_x	HC	CO	NO_x
5,000	0.46	4.79	1.84	0.52	4.24	1.79
10,000	0.53	5.53	1.67	0.66	5.64	1.69
15,000	0.54	5.82	1.73	0.60	4.97	1.66
20,000	0.61	7.24	1.68	0.73	5.73	1.58
25,000	0.61	6.36	1.87	0.73	5.97	1.67
30,000	0.70	6.70	1.82	0.78	5.19	1.72
35,000	0.80	7.65	1.73	0.74	6.09	1.71
40,000	0.66	7.85	1.75	0.81	6.42	1.78*
45,000	0.73	9.31	1.73	0.89	6.58	1.88†
50,000	0.75	9.05	1.83	0.92	7.26	1.85†
Deterioration Factor	1.59	1.84	1.01	1.61	1.48	1.10

*13 Cars †12 Cars

TABLE Ethyl-5
Immediate Effect of MMT on Vehicle Emission Level
1975 CVS Test Procedure

Car	Base Fuel				Base Fuel + 0.125 g Mn/gallon		
	HC	CO	NO_x		HC	CO	NO_x
1972 Make R	3.89	25.44	3.90		4.13	24.28	3.72
1972 Make R	3.54	23.72	3.16		3.58	22.04	2.90
1972 Make F	3.14	46.62	3.68		3.27	46.07	3.64
1972 Make B	2.60	11.41	6.10		2.65	12.48	6.59
1973 Make D	1.48	25.75	1.74		1.44	22.13	1.78
1972 Make D	1.51	27.54	3.79		1.71	30.63	3.91
1972 Make D	2.61	37.66	3.77		2.68	33.55	3.41
1972 Make B	2.30	18.58	3.15		2.31	20.35	2.82
1972 Make A	2.15	26.34	6.40		2.09	25.25	5.94
1971 Make A*	0.33	4.70	2.1		0.34	4.90	2.0
1970 Make BD	11.28	125.19	0.80		10.84†	121.93†	0.65†
Average	3.17	33.90	3.51		3.18	33.06	3.40
				% Change	0	−2	−3

*With Ethyl Lean Reactor
†Tested [illegible] Mn/gallon

there was no catalyst plugging below 1500°F and is a function of catalyst support and location of catalyst relative to exhaust port. Further work is needed in this area.

Ethyl reported no difference between the base fuel and MMT additive fuel on particulate, sulfate or aldehyde emissions. Both these unregulated emissions and the health effects of manganese need further study.

7.2.3 Gould

Gould, Inc., a multi-divisional organization with headquarters in Chicago, has been involved in the development of metallic NOx catalysts for several years. Gould's interest in catalyst development was precipitated by materials requests made of Gould's "Clevite" bearing division by Ford and Chrysler. The auto industry was familiar with Gould as an OEM supplier of components. Other Gould products include; copper foil (for circuit boards), dry cell batteries, small electric motors, torpedoes, powdered metal products, rubber suspension components, air filters and oil filters.

The Gould catalysts are designated as "GEM" (Gould Emission Material) followed by a number (e.g., GEM 45, GEM 67, GEM 68) to designate specific versions of the catalyst. Gould's catalyst, a monel based metallic catalyst deposited on a metallic wire mesh, demonstrated very high efficiency on several test vehicles (most built by Gould) but the durability aspects were questionable. Several automobile manufacturers reported catastrophic catalyst failures at low mileage. Even the best data, accumulated by Gould, showed rapidly decreasing efficiency beginning at around 20,000 miles. It appears that the lack of sophisticated fuel metering systems and air metering systems on the prototype vehicles was responsible for much of the poor durability performance.

Gould has also theorized that the durability problems were due to poor metering and they felt the amount of catalyst deterioration was proportional to the frequency of lean excursions (too much air entering the engine per unit of fuel).

Gould continued to invest in NOx catalyst development with efforts devoted to finding a way to solve the poor metering induced problems without actually improving fuel metering. Instead of relying on outside sources to develop a fuel metering system that would keep oxygen spikes (as occur on lean excursions) from reaching the NOx catalyst, Gould has developed a triple bed catalyst system to solve the problem. In front of the usual two beds (NOx catalyst and oxidation catalyst) is a small oxidation catalyst that functions as an oxygen remover. With this system installed lean excursions no longer affect the NOx catalyst because the O_2 remover, or "Getter", eliminates the oxygen before it reaches the NOx catalyst. A schematic of Gould Getter system is shown in Figure Gould-1.

EPA has previously reported vehicle durability testing results for GEM 68 systems. Table Gould-1 shows 25,000 mile results for three cars.

Table Gould-1

25,000 Durability Results
Gould Getter System Test Cars

Vehicle	HC	CO	NOx	75 FTP MPG	1975 Counterpart
4500 IW. 351 CID with EGR (3 test avg.)	.47	2.5	.33	12.3	11
4500 IW. Chevrolet 350 CID with EGR (4 test avg.)	.42	3.4	.38	13.7	13
4500 IW. Chevrolet 350 CID with EGR (2 test avg.)	.76	4.7	.27	12.9	13

These results are impressive in light of the fact that no advanced HC control techniques were used and the EGR systems were nonproportional units. However, an important factor which has been discovered within this past year clouds the picture on these and other Gould results. This is the deleterious effect of fuel sulfur on GEM 68. Testing has

GOULD GETTER SYSTEM

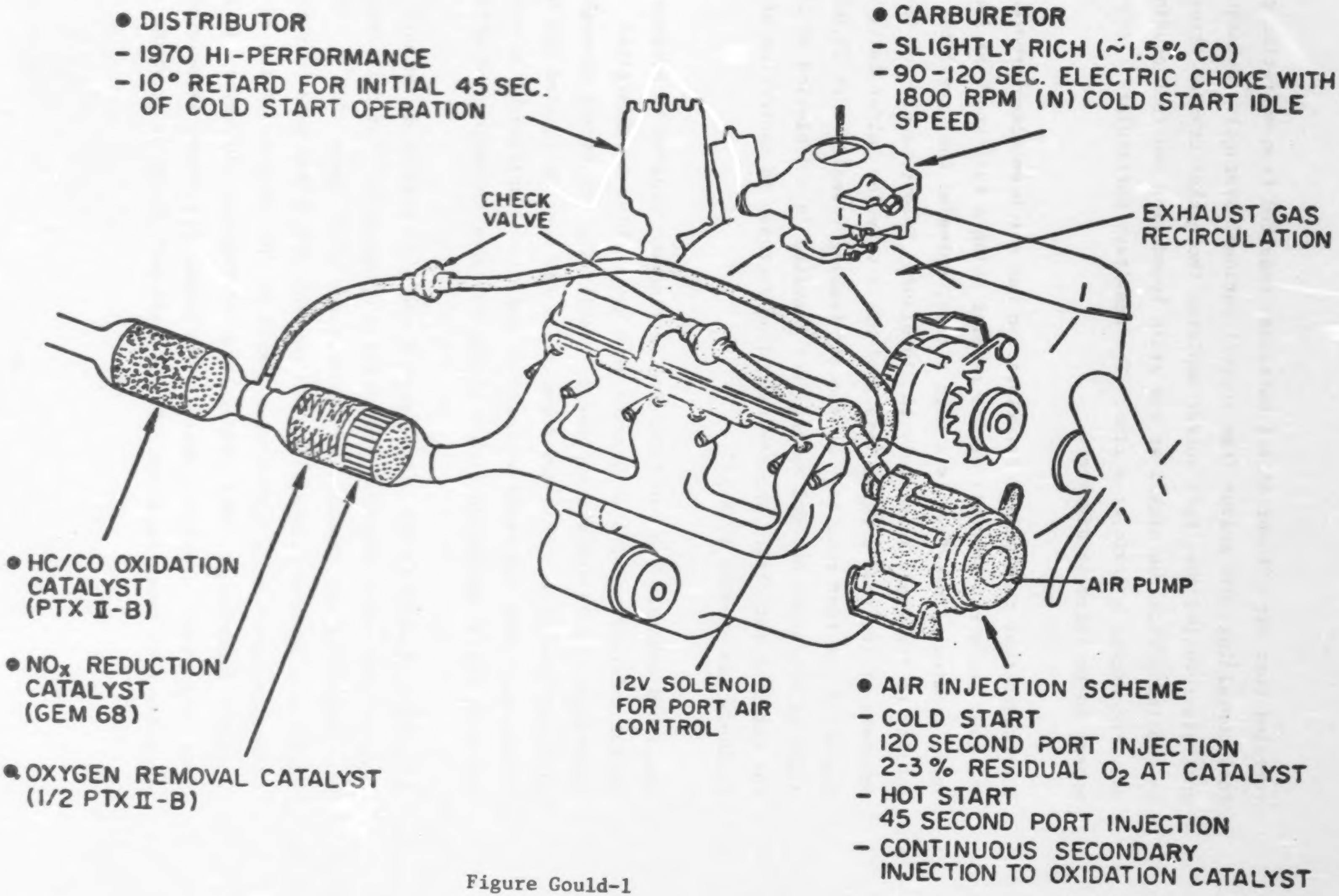

• DISTRIBUTOR
- 1970 HI-PERFORMANCE
- 10° RETARD FOR INITIAL 45 SEC. OF COLD START OPERATION
• CARBURETOR
- SLIGHTLY RICH (~1.5% CO)
- 90-120 SEC. ELECTRIC CHOKE WITH 1800 RPM (N) COLD START IDLE SPEED
CHECK VALVE
EXHAUST GAS RECIRCULATION
AIR PUMP
• HC/CO OXIDATION CATALYST (PTX II-B)
• NO$_x$ REDUCTION CATALYST (GEM 68)
• OXYGEN REMOVAL CATALYST (1/2 PTX II-B)
12V SOLENOID FOR PORT AIR CONTROL
• AIR INJECTION SCHEME
- COLD START
120 SECOND PORT INJECTION
2-3% RESIDUAL O$_2$ AT CATALYST
- HOT START
45 SECOND PORT INJECTION
- CONTINUOUS SECONDARY INJECTION TO OXIDATION CATALYST

Figure Gould-1

revealed that significant nickel emissions resulted from operation on fuel containing .03% sulfur (the current national average). Subsequent analysis revealed that fuel sulfur depletes the nickel crystal structure by combining with the nickel at the grain boundaries and thus eroding away the nickel a grain at a time. The resultant particulate sizes appear to be large in diameter.

The reason that this sulfur deterioration had not been discovered earlier was that Gould has done all of its testing using a fuel known as Amoco Super Premium. This fuel is a high octane, unleaded fuel available locally to the Gould laboratory in Cleveland. Unfortunately for the purposes of the test program this fuel has a very low sulfur level which distorted the test results. Subsequent testing revealed that 25,000 miles of operation on .02% sulfur fuel resulted in a depletion of 22% of the catalyst material. The corresponding decrease in conversion efficiency was greater than 22%.

Gould had embarked upon an intensive development program to produce a sulfur tolerant catalyst. Drawing upon gas turbine metallurgical techniques, Gould reports success in stabilizing the nickel through an alloying procedure. This new formulation has been designated GEM 69. Preliminary data has shown an order of magnitude improvement in resistance to sulfur depletion with a slight decrease in conversion efficiency.

A critical factor in the efficiency of Gould's catalyst is exhaust gas temperature. Ford reported steady state dynamometer test data showing low conversion efficiencies at temperatures below about 1000°F. This could be a serious drawback for NOx control during the warm up period. Gould disputes Ford's claims with regard to the severity of the efficiency decrease at lower temperatures by pointing out errors in Ford's test techniques. However, Gould acknowledges the strong temperature dependence of their catalyst. Toward this end, Gould is studying engine systems which conserve exhaust gas heat. The base metal NOx catalyst work reported by Chrysler included the tailoring of the engine for exhaust heat conservation via insulated exhaust passage. Unfortunately, Gould does not have ready access to advanced engine systems of this type. This problem is a general one which has hampered the non automobile manufacturers from the very beginning.

Gould has continued its work with the major domestic automobile manufacturers over this past year. These efforts have been discussed in the sections dealing with the individual manufacturers. The results of these evaluations have been disappointing. A good deal of the problem seems to be related to the need of the GEM 68 system for an engine system that is well tailored to its individual requirements. Particularly important are fuel metering and exhaust gas temperature. In the area of fuel metering the Gould system needs a slightly rich mixture with minimal lean excursions under transient conditions. Exhaust gas heat conservation, utilizing devices such as exhaust port liners, is important to maximize the GEM 68's conversion efficiency. To date the manufacturers have not been successful in putting together systems which satisfy these requirements.

EPA entered into a contractual relationship with Gould in May of 1975 for the purpose of demonstrating catalytic control of NOx. This contract resulted from a competitive procurement which was not constrained to the dual catalyst approach. Under the terms of the contract Gould is to build up three cars with their GEM 68 system and accumulate 50,000 miles of AMA testing on each car. Initial delays were experienced due to difficulties with hardware procurement and vehicle calibration. More recently the emergence of the sulfur tolerant formulation, GEM 69, has resulted in a temporary suspension of activity.

Progress and Problem Areas

Gould experienced a major setback with the discovery of the sulfur deterioration of GEM 68. However, it appears that Gould has surmounted this problem with the development of GEM 69. However, vehicle tests to substantiate the degree of the improvement have not yet been run.

A major problem for Gould has been their inability to secure fully optimized engine systems that are tailored to the special needs of their catalyst. The full recognition of some of these needs such as exhaust gas heat conservation has come only recently. The logical solution to this problem would be a dedicated effort on the part of the automobile industry to provide well optimized, full effort systems.

Indications are that unless a 1.0 NOx standard or below is instituted at least in California by 1979 or 1980, Gould will not wish to continue further investments in the NOx catalyst.

7.2.4 Yamaha

Since the issuance of the last status report, Yamaha has continued developments of the Yamaha Lean Combustion Engine System. The Yamaha system is a combination of engine modifications consisting of a lean carburetor coupled with intake manifold and cylinder head modifications and an air gap insulated exhaust manifold for post-cylinder oxidation reactions to facilitate low emissions. The first EPA test results obtained last year while impressively low, were not able to meet the 1977 emission levels with good fuel economy as shown by the first three data points of Table Yamaha-1. It was apparent that much of the poor fuel economy performance was due to the fact Yamaha attempted to achieve 1977 standards without catalytic aftertreatment and had to resort to spark retard to control emissions.

Subsequently Yamaha reported the improved data on line four of Table Yamaha-1 and EPA again ran confirmatory testing of the system. These results are shown by the third series of data (lines five, six and seven of Table Yamaha-1). The fuel economy results of the first set of data were lower than comparable 1974 Corolla results, while the second EPA series showed fuel economy results comparable to vehicles of the same inertia weight class.

The latest two-page Yamaha submission, which was brief, incomplete, and not responsive to EPA's request, provided the results of two additional vehicles which use the YLCS in combination with catalysts. The brevity of the submission precluded analysis or technical understanding of what control technologies were indeed developed. It is unclear, for example, if the data on the 2.3 liter engine reported as "catalyst & EGR" also included the post-cylinder thermal reactor manifold integral to the Yamaha system. EPA views heat conservation techniques coupled with exhaust aftertreatment as an effective approach to achieving future standards while retaining good fuel economy. Because of the nature of their approach the Yamaha system cannot be truly assessed for its potential, since practically nothing of use was submitted.

Yamaha did report that they were continuing effort to reduce NOx levels and improve fuel economy. Additionally, they are studying the costs and vehicle performance of both the catalytic converter and the lean reactor.

It is concluded that the 2.3 liter and 2.0 liter engine as reported would have a good chance of attaining certification if the YLCS were installed in a durability vehicle. Further work is needed by Yamaha to show the true potential of their approach.

Table Yamaha-1

Yamaha Lean Combustion Engine System

		75 FTP grams/mile			Fuel Economy		
Vehicle	Inertia Weight	HC	CO	NOx	MPG	MPG	Remarks
Corolla[*]	2250	.36	3.80	1.18	16.0	28.7	No catalysts
Celica[*]	2500	.34	2.95	2.95	14.5	23.6	No catalysts
Celica[*]	4000	.46	6.87	2.32	14.7	19.4	No catalysts
Corolla[**]	2250	.28	2.87	1.87	22.3	34.1	No catalysts
Corolla[∅]	2250	.39	3.29	1.45	23.1	35.3	No catalysts
Corolla[∅]	2250	.31	2.87	1.48	23.8	36.0	No catalysts
Corolla[∅]	2250	.33	2.85	1.40	23.9	37.5	No catalysts
Unspecified[**]							
2.3ℓ - 4M trans	3000	.33	3.00	1.8	20.2	28.5	Thermal reactor and EGR
2.3ℓ - 4M trans	3000	.26	1.20	1.7	22.8	32.8	Catalyst & EGR
2.3ℓ - 4M trans	3000	.21	.90	1.0	22.7	33.2	Catalyst & EGR
Unspecified[**]							
2.0ℓ - 5M trans	2750	.05	0.9	1.4	18.3	30.1	Thermal reactor and EGR

[*] Data Source: EPA Test Report 75-8.

[**] Data Source: Yamaha submission to Status Report Team.

[∅] Data Source: EPA Test Report 75-16.

7.2.5 Questor

Questor is another multi-divisional company with experience in supplying componetry (exhaust systems) to the auto industry. The emission control system being developed by Questor Inc.,called the "Reverter" System, is basically a rich thermal reactor, followed by a metallic NOx catalyst, followed by another thermal reactor. No oxidation catalyst is used, and the system is lead tolerant. A schematic of the system appears in Figure Questor-1.

Three years ago, the Reverter system was evaluated by the report team as having at least as much, if not more, potential for attaining the .41 HC, 3.4 CO, 0.4 NOx level as any system that the automobile manufacturers were developing, but that the manufacturers were apparently not interested in the system since it was not compatible with their 1975 oxidation catalyst systems.

Three years ago Questor was actively working on improvements to the Reverter system. One of the drawbacks to some of the early generation Questor systems was their relatively poor fuel economy, which resulted from the rich operation required to keep the reactors and the catalyst hot enough to work efficiently. Typical idle CO values for these early prototypes were 7 to 9 percent, with a resulting fuel economy penalty of up to 20 percent compared to current vehicles. Questor has worked to improve the fuel economy of the system by using a third generation packaging configuration that reduces the heat loss, and by running leaner. This has allowed Questor to reduce the CO level down to between 1 1/2 and 3%. In order to keep the NOx levels down, Questor worked with metal suppliers to develop improved NOx catalysts that are more active. Questor estimated that with the latest systems the .41 HC, 3.4 CO, 0.4 NOx levels could be met with no fuel economy penalty over 1974 vehicles.

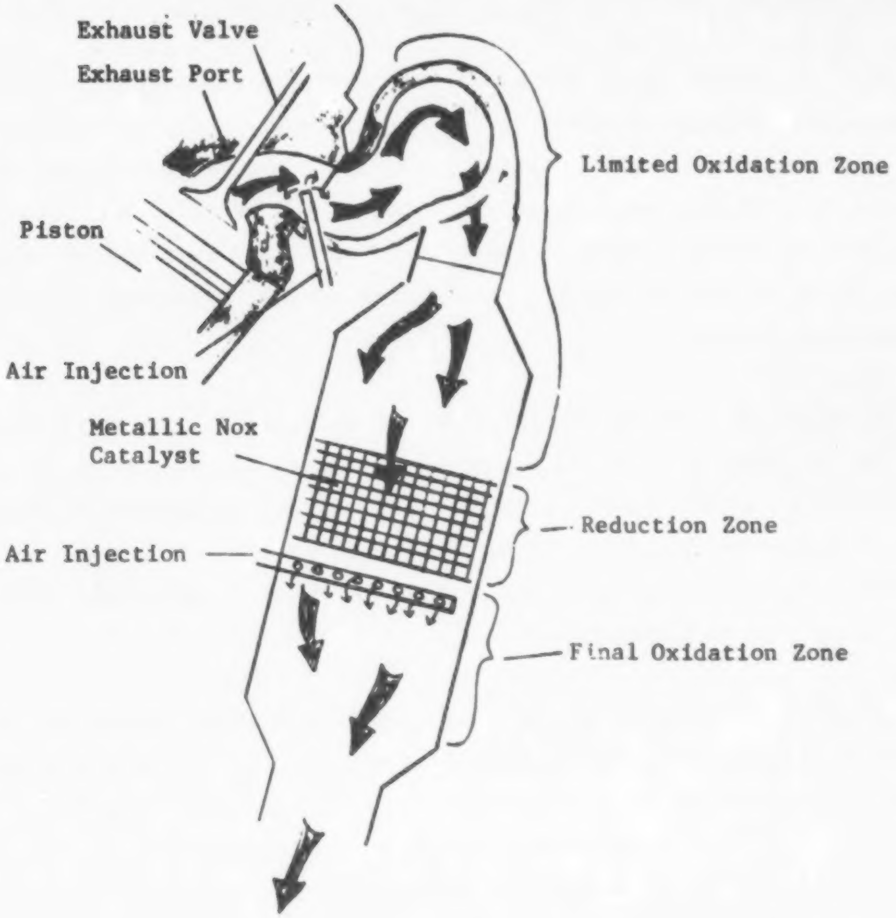

Exhaust Valve
Exhaust Port
Limited Oxidation Zone
Piston
Air Injection
Metallic Nox Catalyst
Reduction Zone
Air Injection
Final Oxidation Zone

Figure Questor-1
Questor Reverter System

The best emission and fuel economy results achieved to date are reported in Table Questor-1. Note that the EPA Certification fuel economy figures are for the baseline cars (1974 Pinto and 1973 Datsun). The 1976 Certification fuel economy figures for corresponding models would be higher.

Table Questor-1

Questor Reverter System

	Emissions			Fuel Economy		% Change
Vehicle	HC	CO	NOx	Questor	EPA Cert.	Cert. to Questor
1974 Pinto 3000 IW, 2.3ℓ	0.11	2.74	0.32	18.4	17.1	+7.6
1973 Datsun 2750 IW	0.13	2.6	.21	20.1	18.6	+8.7

The most significant durability testing reported for the Questor system over this past year was done by Nissan Motor Company. Table shows the reported data. The Reverter failed somewhere between 20,000 and 25,000 miles due to a weld failure. Questor claims that they have corrected this type of failure on succeeding units.

Cooperative Programs

Questor reports that starting in July 1975 the interest levels of all of the domestic automobile manufacturers have shown a significant increase. Programs are reportedly being developed at each manufacturer for joint development.

Progress and Problems

Questor's major problems have not been the achievement of the required emission levels, which they have successfully demonstrated time and again.

Table Questor-2

Questor Durability
1973 Datsun, 1.8 liter

Mileage	HC	CO	NOx	MPG
5,000	0.29	4.70	0.53	19.0
5,000	0.20	2.60	0.31	17.9
10,000	0.28	4.48	0.25	15.9
10,000	0.19	3.13	0.21	15.8
15,000	0.27	3.87	0.17	16.6
15,000	0.22	3.33	0.20	17.8
20,000	0.28	5.77	0.24	16.6
20,000	0.21	3.58	0.23	17.3
25,000	0.37	5.98	3.55	19.4
25,000	0.76	15.50	0.14	16.3

Questor's problems have been fuel economy and system durability. As previously explained the fuel economy problem has been alleviated somewhat by the reduction in the required CO level. A decrease in system temperature of approximately 200°F was tied into the CO level decrease. This temperature decrease should help alleviate Questor's other major problem - durability. Questor has been plagued with Revertor weld failures. Another durability problem has been air pump failures. The higher air flow needs of the Questor system have compelled Questor to spin the standard pumps at higher speeds than they were designed for. This is an area where the cooperative development programs with industry can help Questor by providing higher capacity pumps. Questor also needs improvement in the control and management of the secondary air. Both improved air scheduling and component durability are needed. Help is also needed in the engine optimization area. A critical factor in NOx reduction efficiency is the minimization of the O_2 passing through the NOx reduction catalyst bed. This becomes a problem during off-idle and acceleration modes when enleanment occurs causing both higher NOx production and reduced Reverter efficiency because of O_2 in the NOx catalyst bed. Industry help in reducing these transient enleanment conditions is needed.

Questor presented an analytic discussion in their status report showing that based upon chemical equilibrium relationships, there should be very low SO_3 production in their Reverter. Testing of a Questor equipped Pinto at Southwest Research Institute verified this analysis by showing a H_2SO_4 production rate of only .3 milligrams per mile on the 75 FTP and 6.2 milligrams per mile on the highway fuel economy test. This is comparable to uncontrolled cars.

7.3 Foreign Manufacturers

7.3.1 BMW

BMW did not submit a status report. They did, however, submit a preliminary Part I application, on which this discussion is primarily based.

Systems to be Used - 1977 Model Year

BMW will continue to have two basic engines for 1977. The 4-cylinder (family 120.9) and the 6-cylinder (family 130.8).

The systems to be used are shown below in Table BMW-1.

Table BMW-1

Systems to be Used
1977 Model Year

Engine Family (Model)	1977 Federal	1977 California
120.9	EM* + K Jetronic + EGR + Air Injection	not reported
130.8/530$_i$/630C5$_i$	L-Jetronic + EGR + Thermal Reactor + Air Injection	L-Jetronic + EGR + Thermal Reactor + Air Injection

* EM = Engine Modifications.

The emission control system for the 4-cylinder engine has not reported, but if the system used on the 6-cylinder engine is any indication, the use of a thermal reactor appears to be the approach likely to be taken by BMW. A thermal reactor was used on some earlier 4-cylinder models with certification results as low as 0.4 HC, 5.4 CO, 1.4 NOx.

The only difference between the 1977 Federal and California systems is a different distributor for the California version with a slower centrifugal curve and more vacuum retard. Thermal reactor maintenance is planned at 25,000 miles, but the type of maintenance is unspecified.

Systems to be Used - Post-1977 Model Year

Since BMW did not submit a status report, their program to meet future emission levels is difficult to discuss. Their earlier status reports indicated that they were working on dual catalyst, 3-way catalyst and stratified charge engine approaches. Since BMW already will use fuel injection for both of their models, the 3-way catalyst route appears to be a logical area for them to explore.

Progress and Problems

BMW is only in the early stages of 1977 certification but there appear to be no major problems for them for the model year 1977 Federal or California standards in the 6-cylinder engine. For the 4-cylinder engine they still apparently have not decided on a control system for California.

As far as future standards go, BMW's capability is impossible to determine.

7.3.2 British Leyland (BL)

Systems to be Used

Systems to be Used - 1977 Model Year

BL reports that their 1977 model year systems will be comprised of AIR, EGR and oxidation catalysts. BL is determined to eliminate the use of catalyst change for 1977 models. Five of BL's eight engine families for 1976 relied on catalyst changes. All of these families were certified for California and as a result BL was compelled to pay the cost of the catalyst changes. BL is counting on improved catalyst technology e.g., formulation/washcoat/substrate, to provide sufficient durability to go 50,000 miles without a change.

Aside from improved catalysts, the only other emission control development applicable to the 1977 model year described by BL is a new carburetor developed by Zenith. Called the fully automatic start device (FASD), the carburetor does not have to be triggered i.e., depressing the accelerator to engage the cold start circuitry. BL also indicates that this carburetor uses a very high flow and achieves better metering over the range of engine speeds and ambient conditions. This device will be fitted to one Triumph model for 1977. BL did not provide cost or fuel economy data for the 1977 model year.

Systems to be Used - 1978 Model Year

BL has stayed with the dual catalyst approach as for the .41 HC, 3.4 CO, 0.4 NOx level. BL indicates that "work is less intensive than previously" and states further that it has been difficult to obtain improved reduction catalysts to test because catalyst manufacturers are concentrating on three way catalyst development.

BL's system for this level also includes proportional EGR. Their prototype systems have insulating material applied to the exhaust manifolds.

BL reports work on three way catalyst systems and describes these systems as candidates for the .41 HC, 3.4 CO, 1.0 NOx level. Their best results at zero miles have reportedly been .29 HC, 3.4 CO, 1.0 NOx. BL did not provide any description of the vehicle or system with which these values were obtained.

BL has resurrected a manifold catalyst program based upon the promise of higher temperature tolerant catalysts. Some test results were presented showing significant HC reductions compared to a conventional catalyst installation. Table BL-1 shows these results.

Table BL-1

Manifold Catalyst System
TR7 V8
hot 505 second portion of FTP

	HC	CO	NOx
Manifold Catalyst	0.18	1.17	0.75
	0.12	1.10	0.74
Conventional Catalyst	0.29	0.84	1.57
	0.23	1.54	1.7

BL reports that work is continuing on the Shell Vapipe system. This system uses a heat pipe to transfer heat from the exhaust gas to intake air fuel mixture. No new data was reported. The Vapipe has not shown much promise to date principally because it is slow in warming up.

More work was reported on BL's stratified charge engine program. A new 110 cu. in. engine has reportedly been built that is based upon a gasoline engine.

The description was sketchy but it appears to be a carbureted three valve per cylinder type. No data was reported but BL indicates that the specific output is higher than their former stratified charge engine, a reworked diesel.

Thermal reactor work has continued at BL "at a low level of priority". Only one 75 FTP test was reported with the results showing a small decrease in HC. BL claims that to effectively reduce emissions a rich mixture corresponding to a 15% fuel economy penalty must be used.

Durabiltiy Testing Programs

Durability Testing Programs - 1977 Model Year

BL is expected to run durability on both catalyst change vehicles and 50,000 mile catalyst vehicles. This will insure their ability to certify cars for California even if the 50,000 mile catalyst vehicles do not make it.

Durability Testing Programs - 1978 Model Year

Durability testing on a two dual catalyst systems was reported for this past year. Both used noble metal ICI reduction catalysts. A 1.8 liter Marina accumulated 27,400 miles before being terminated due to loss of HC and CO control. NOx control on this car was .36 gpm at time of termination. The second dual catlayst system completed 18,797 miles but was stopped for a catalyst change because of loss of HC and CO control. NOx control was .31 gpm at this mileage.

A Jaguar XJ6 finished 50,000 miles of durability with a GKN thermal reactor. Emissions at 50,000 miles were .32 HC, 6.37 CO, and 1.13 NOx.

Progress and Problems

Progress and Problems - 1977 Model Year

BL's major concern is certifying without a catalyst change. Progress has been made in catalyst technology.

Progress and Problems - 1978 Model Year

BL's major problems at the .41 HC, 3.4 CO, 0.4 NOx level is a lack of effort. Dual catalyst and three way systems are receiving little attention. The underlying problem may be BL's financial conditions although BL did not state this.

7.3.3 Citroen

Citroen has not marketed vehicles in the United States since the 1974 model year. They did however respond to the EPA request for information regarding Citroen's development status and progress toward meeting the 1977 and 1978 emission standards. Because of the brievity of the report, it is difficult to determine what systems could be introduced in the post-1977 model year time frame. Citroen did note that they are not actively marketing new vehicles in the U.S. at present and it was concluded that they have no intention of marketing 1977 or 1978 models. Also missing from their status report submissions was any discussion of their Diesel engine program. Their report did not include any durability data, fuel economy, cost, nor any oxides of nitrogen data.

Systems Considered - 1977 Model Year

At levels of 1.5 HC, 15.0 CO, 2.0 NOx, Citroen considers three systems, namely air injection, oxidation catalyst without air injection, and the lean thermal reactor. EGR was used in all cases. The latter two were rejected because of poor driveability. The prefered systems will be used on a 4 cylinder, 9 to 1 compression ratio, 2 barrel carburetor, 2.2 litre engine with an air pump. EGR is venturi vacuum controlled. The reported emissions results were 1 g/mile HC and 10 g/mile CO. No fuel economy nor NOx levels were reported. Citroen feels that this system would be adequate for several reasons which include; use of high compression ratios for better fuel economy, no safety hazard associated with use of a catalyst, engine calibration optimization, and system non-deterioration and reliability.

For the 1977 California levels two systems for the same engine as the 49-state version were considered; a rich thermal reactor plus EGR, and oxidation catalyst, air injection and EGR. Citroen added a high idle speed at cold start, 2000 rpm engine speed for 20 seconds after hot start, and retarded ignition timing to the rich reactor concept so it may meet the 3.4 CO standard. They reported a 13.4 mpg urban fuel economy for this concept. No emission results were given. Citroen feels a 10% fuel economy benefit will be achieved by only attaining 9.0 CO. For the catalyst concept, they lowered the compression ratio to 8 to 1, used a 2/3 Pt, 1/3 Pd noble metal loaded catalyst and port air injection. They reported poor light-off initially, and by using an improved exhaust manifold experienced lower output power and higher fuel consumption. Work continues to improve catalyst life. They presently predict a catalyst change, at unspecified mileage, improved fuel economy, and increased air injection rates.

Durability Testing Programs

Citroen did not report any durability data in their status report. They did report the deterioration factors and catalyst efficiencies for the oxidation catalyst concept previously mentioned. The DF's were 1.63 for HC and 1.20 for CO. The efficiencies were 62% for HC and 63% for CO at 25,000 miles and 53% for HC and 59% for CO at 50,000 miles. No NOx results were given. Fuel consumption was reported to be approximately 18 mpg, with the vehicle unspecified.

Progress and Problem Areas

The question of progress and problems may be a moot question for Citroen since they apparently are not planning to market vehicles in the U.S. However, it would seem from their brief discussion of systems that considerable work will be necessary to attain the California levels. If difficulties are apparently encountered at .41 HC, 3.4 CO, the ability to meet the statutory 1978 levels are seriously doubted. It is concluded that the Citroen emission control status would effectively limit introduction of Citroen vehicles to America. If their capabilities are otherwise, it was impossible to judge so from their status report. For example, no tests were reported with their Diesel engine which may have led to this negative conclusion.

7.3.4 Daimler-Benz

7.3.4.1 Systems to be Used

Systems to be Used - 1977 Model Year

The 1977 Daimler-Benz (DB) systems will be as shown in Table DB-1. All gasoline engine families except the inline 4-cylinder (L-4) will use the Bosch "K-Jetronic", mechanical fuel injection system. The 4.5 liter V-8 will use a reed valve (R) air injection system. Both the Federal L-4 and California L-6 gasoline models will use what DB calls a "dual bed" catalyst. Actually the L-4 uses two monolithic catalysts in a single container with air injected between the two monoliths. The first monolith performs the reducing function and second performs the oxidizing function. The L-6 uses three monolithic catalysts in three separate containers. The first two are relatively small and are located just

Table DB-1

1977 Emission Control Systems

Family	Standards	Otto or Diesel Cycle	AIR	EGR	Ox. Cat.	Dual Bed Cat.
M115(L-4)	50 State	Otto	x	x		x
M110(L-6)	Federal	Otto	x	x	x	
M110(L-6)	California	Otto	x	x		x
M117(V-8/4.5)	Federal	Otto	R	x	x	
M117(V-8/4.5)	California	Otto	x	x	x	
M100(V-8/6.9)	50 State	Otto	x	x	x	
OM-616(L-4)	50 State	Diesel				
OM-617(L-5)	50 State	Diesel				

behind the split exhaust manifolds. These two perform the reduction function. They are followed by a larger oxidizing converter. The reduction catalysts for the L-6 were called "selective" or 3-way catalysts. They apparently are 3-way catalysts operating on the rich side of stiochiometry. The reducing unit for the L-4 was not fully described and could be either a catalyst which performs only reduction after warm up or also a rich biased 3-way catalyst which could perform reduction and some oxidation after warm-up. The AIR systems on the dual bed catalyst vehicles will be switched from the exhaust port to between the catalysts after warm up.

The Diesel engines are still essentially uncontrolled, and use only reverse flow damping valves (check valves), in the injection lines for HC control.

Daimler-Benz did not revise their cost estimates from last year. So assuming the cost estimates for .41 HC, 3.4 CO, 2.0 NOx to be appropriate for the 1977 California levels, the initial cost increase of the DB gasoline models for California will be about $22 for the L-4, $193 for the L-6, and $63 for V-8/4.5 The V-8/6.9 will be a new addition for 1977 and cannot be compared to 1976. For the L-6, $140 of the $193 increase will be for the change over from carburetion to fuel injection. Maintenance cost is not expected to change when compared to the 1976 models. The cost of altitude compensation for the Diesels was said to be about $18. No costs were given for attitude compensation on the gasoline models. The respective fuel economies of 1976 model year durability vehicles and 1977 prototype durability vehicles are presented in Table DB-2. It can be seen that both 1977 Federal and California vehicles have fuel economies similar to the 1976 certification vehicles, except for the L-4 gasoline engine which is down slightly. No percent changes in fuel economy were calculated as DB has stated that

DB- 2

Fuel Economy Comparisons

		'76 Federal Durability Vehicles		'77 Federal Prototype Vehicles			'77 California Prototype Vehicles
Engine	Otto or Diesel Cycle Engines	No. of tests	Avg. MPG$_U$	No. of tests	Avg. MPG$_U$	No. of Tests	Avg. MPG$_U$
L-4	Otto	15	16.11	19	16.07	7	13.95
				22	14.39	9	15.01
				21	15.29		
L-6	Otto	15	13.01	24	13.26	7	12.83
						5	13.08
V-8/4.5	Otto	15	10.84	44	10.66	11	10.82
				28	10.70	21	11.36
				25	11.27		
				13	10.73		
L-4	Diesel	15	24.30	18*	24.64		
				19*	26.22		
				12*	26.09		
L-5	Diesel	15	23.34	5	23.35	18*	23.9
				14	23.05		
					23.77		

*Research vehicle, not durability vehicle fuel economy optimization at the 1977 levels has not been completed, and that the main objective for the durability vehicles was to achieve the given emission levels.

Systems to be Used - 1978 Model Year and Beyond

DB reported that their first choice system for all their 1978 gasoline-fueled vehicles would be EGR, AIR, and dual bed catalysts. They indicated that 0.4 NOx had been very difficult to achieve even at low mileage. Since DB did not report emission control system changes between individual tests on their vehicles, their emission stability problems could not be evaluated.

Despite the emission results in Table DB-3 which were reported by DB to EPA in 1973, DB maintains that the Diesel probably cannot achieve NOx emission levels much below 1.5 gm/mi. Hot test results can be compared to cold-start results for NOx for Diesels, according to DB. The 1973 report also included at least 15 other data points where NOx emissions were between 0.5 and 1.0. The data shown in Table DB-4 were reported this year. The average fuel economy of a comparable 1976 certification durability car was 24.3 MPG.

Table DB-3

Diesel Data Reported by DB in February, 1973

Date of Test	VIN	HC	CO	NOx	Test Cycle
11/09/72	D89	.37	2.52	0.32	Hot FTP
11/09/72	D89	.29	2.24	0.23	Hot FTP
12/12/72	D89	.20	2.16	0.49	
4/27/72	D141	.04	0.55	0.50	Hot FTP
4/27/72	D141	.08	0.55	0.45	Hot FTP

Table DB-4

More Recent Diesel Test Results

Date of Test	VIN	HC	CO	NOx	MPG_U	Test Cycle
4/10/75	W115-D24-140	.131	1.605	.811	27.90	Hot FTP
7/9/75	"	.194	2.381	.775	25.58	Hot FTP
7/10/75	"	.220	2.355	.767	26.36	Hot FTP
9/2/75	"	.172	2.341	.899	26.74	Hot FTP
9/5/75	"	.225	2.332	.892	25.20	'75 FTP
9/11/75	W115-D24-184	.196	1.747	.788	25.42	Hot FTP
9/12/75	"	.234	1.610	.866	25.82	Hot FTP

The initial cost increases for the 1978 gasoline modesl were also not revised, but range from $198 to $430 over the 1976 models. The fuel economies of prototype DB vehicles which achieved the statutory emission levels shown in Table DB-5.

Table DB-5

Low NOx Testing of Gasoline Powered Vehicles

VIN	Engine	HC	CO	NOx	MPG
W116E28-165	L-6	.37	2.64	.39	14.20
"	L-6	.37	2.52	.32	14.75
W116E45-62	V-8/4.5	.26	1.49	.19	9.84
"	"	.22	2.49	.18	11.07
"	"	.33	1.11	.22	9.64
"	"	.37	1.27	.38	9.84
"	"	.37	1.36	.39	10.25
"	"	.30	2.50	.24	10.65
"	"	.15	.76	.31	10.40
"	"	.23	.85	.32	10.35

Other Systems

DB reported work on backpressure EGR and lead tolerant catalysts. No data was presented using the EGR systems. Some lead tolerant catalyst data was presented, but the catalysts deteriorated rapidly.

Data was presented for a vehicle using a four cylinder, stratified charge engine. The engine and emission control system were not described. Some of the better data for this vehicle are presented in Table DB-6.

Table DB-6
The DB Stratified Charge Vehicle

HC	CO	NOx	MPG
.45	.654	1.132	16.14
.44	1.24	1.180	16.07
.53	.64	.85	15.17
.36	.52	1.35	22.75

A significant amount of data was also presented for turbocharged Diesels. Some of the data for a 5 cylinder model at 4000 lb. IW are shown in Table DB-7.

A vehicle with the Comprex, pressure wave supercharger was tested at EPA over the past year. The emission results are found in Table DB-8. The vehicle was equipped with a 134 CID engine and had 0-60 mph acceleration performance of about 18 seconds. The supercharger had some problems, including noise, but it had the advantage of being able to provide EGR without the addition of any more hardware. DB apparently has discontinued work on the Comprex in favor of conventional turbochargers. No further work on the V-8 Diesel, the 450D, was reported by DB.

Table DB-7

Turbocharged Diesel Results

Mileage	HC	CO	NOx	MPG_U
4232	.26	1.14	1.69	24.18
6494	.16	1.08	1.31	28.91
7005	.17	0.96	1.49	28.79
8648	.14	1.26	1.11	29.11
12726	.23	1.15	1.10	30.01
15573	.10	.95	1.35	27.10
18587	.16	1.13	1.55	25.72

Table DB-8

Comprex Vehicle Test Results

HC	CO	NOx	MPG_U	MPG_H
.23	1.35	1.39	24.8	34.8
.29	1.34	1.39	25.1	33.8

7.3.4.2 Durability Testing Programs

Durability Testing - 1977 Model Year

DB has operated thirteen gas and four Diesel durability vehicles. Because mileage points were not given for the majority of durability tests reported, it is difficult to assess DB's capability to certify in 1977. For those gasoline vehicles which did have specified mileage points, DB appeared to be having problems meeting .41 HC and 1.5 NOx simultaneously. All of the Diesels were targeted for 2.0 NOx, though some were near 1.5 consistently. Emissions of HC and CO for the Diesels were generally well below .41 HC and 3.4 CO.

7.3.4.3 Progress and Problem Areas

Progress and Problems - 1977 Model Year

DB should have few problems for 1977 Federal certification. Perhaps the biggest question mark is the durability of the new dual bed catalyst system for the L-4 gasoline family. If their 1977 California durability cars are no better than the durability vehicles reported, DB gas models may do a considerable amount of line crossing. Optimistic data is absent for vehicles equipped with both the oxidation and dual bed catalyst systems. The Diesels will probably be easier for DB to certify at both the Federal and California levels.

The use of fuel injection and dual bed catalysts plus the testing of closed loop fuel injection systems indicate that DB may be headed for closed loop 3-way plus oxidation catalyst systems in the future. The 1977 dual bed systems may be only an interim step. While many organizations are optimistic about closed loop 3-way control, not many are yet gambling on open loop 3-way control.

Progress and Problems - 1978 Model Year

The lack of durability testing continues to be a problem for DB in 1978. This not uncommon as most manufacturers are counting on a revision of the 1978 emission standards. DB has done considerable low mileage testing of their dual bed catalyst systems. Assuming that their closed loop fuel metering systems progress as expected and that their dual bed catalysts prove durable, DB could soon be in a good position to meet future emission standards.

DB has historically been the leader in Diesel engine emission control for light duty vehicles but until recently few manufacturers were interested in Diesels. DB's position of leadership may be challenged by the manufacturers like VW who are currently, aggressively developing Diesels.

7.3.5 Fiat

7.3.5.1 Systems to be Used

Systems to be Used - 1977 Model Year

The 1977 Fiat control systems will remain virtually unchanged from their 1975-76 systems. The 49-states systems include AIR, spark delay valves, decel modulation, and vacuum modulated EGR. The California system will use the UOP supplied pellet-type oxidation catalyst with an increased loading to .04 troy ounces of platinum from last year's loading of .03 troy ounces. Fiat indicates that there will be no catalyst change for the 1977 models. Fiat retained the catalyst warning system.

Fiat did not provide any cost or fuel economy estimates for their 1977 model year vehicles. However, a review of the 1976 durability vehicles indicates that the increase catalyst will allow Fiat to optimize for better fuel economy in 1976. The 1976 durability vehicles indicated Fiat had vehicles in 1976 which could meet the Federal 1977 levels, while the increase volume catalyst superimposed on the 1976 California vehicles will enable them to meet the 1977 California levels.

Systems to be Used - 1978 Model Year

To meet the 0.41 HC, 3.4 CO, 0.4 NOx levels, Fiat plans to use a dual catalyst system with secondary AIR in conjunction with the basic 1976 California system. Additionally, Fiat is experimenting with three way catalysts and improved EGR systems. From the limited durability data presented by Fiat, it is concluded that Fiat has had limited success with the latter systems. Possibly the development of more sophisticated systems will allow Fiat to close the apparent technology gap with their competitors. Fiat has started basic research into exhaust gas sensors, low thermal inertia exhaust a manifolds, screening test program for various reducing catalysts, and air metering concepts for use with experimental fuel metering systems. Work continues at the research and pre-production stages of these programs. Fiat provided no cost or fuel economy information regarding their potential 1978 systems.

Other Systems

Fiat has continued their efforts on developing pre-chamber stratified charge, Diesel, and gas turbine engines. With the exception of the gas turbine engine, Fiat now has vehicular emission data for these engines. Fiat also reports 17 prototype 2.0 and 2.4 liter Diesel engine accumulating durability. The pre-chamber stratified charge engine single cylinder work has been virtually completed for both the types of engines concepts considered. These concepts are the large, 70% of total combustion chamber volume, pre-chamber engine and the carbureted, 2 valve "torch" combustion engine with a pre-chamber volume of 10% of main chamber volume. The latter concept, installed in a 2 liter engine in a 2500 inertia weight vehicle, produced CVS results of 2.5 to 3 g/mile HC, 7 g/mile CO, and 1.7 g/mile NOx without any other emissions control technique. The former concept is still under consideration but needs work to strengthen engine structrual deficiencies. Fiat's work on the Diesel engine centers on a pre-chamber 4 cylinder 2.4 liter engine which produced emission levels of 0.57 g/mile HC, 2.05 g/mi CO, and 1.45 g/mile NOx with urban cycle fuel consumption of 29.9 mpg in a 2750 pound inertia weight vehicle. Durability on two similar engine/vehicle combinations have accumulated 36,000 and 65,000 miles respectively. Fiat also has accumulated 1000 engine dynamometer durability hours on this prototype engine. Work continues, somewhat more slowly on the 2 liter engine. No work other than turbocharging on Diesel engines was reported. The gas turbine program continues with a vehicle installation and component durability testing. Some consideration is being given to using a Rankine cycle topper with the gas turbine. No emissions or fuel economy data were reported.

7.3.5.2 Durability Testing Program

Durability Testing - 1977 Model Year

Fiat reported durability data from eight vehicles although it was not apparent what the target emission levels were. Fiat should have no trouble meeting the 1977 Federal levels. Fiat is still experiencing HC and CO control problems at the 0.41 HC, and 9.0 CO levels. Additionally, Fiat reported catalyst durability problems on the test vehicles with over 50 percent loss of catalyst materials from most of the test vehicles.

Durability Testing - 1978 Model Year

The dual catalyst vehicle was unable to meet the 1978 emission levels at zero mileage and subsequently sustained a container failure at 5,000 miles. This vehicle had pelletized reduction and oxidizing noble metal catalysts with EGR.

7.3.5.3 Progress and Problem Areas

Progress and Problem Areas - 1977 Model Year

It is difficult to assess the progress Fiat has made since the last status report due to the sketchiness of the Fiat status report. The report submit consists of a series of enclosures, previously submitted to CARB, attached to a brief cover letter. However, from the data presented it would seem that Fiat will be able to market vehicles which meet the 1977 Federal levels. The California vehicles will take additional work. The severity of the catalyst material losses must be characterized and remedied to assure Fiat will not have to have a catalyst change before 50,000 miles. Fiat indicates there will be no catalyst change for 1977. Preliminary indications are that the fuel economy for the 1977 Fiats will be as good as 1976 model year.

Progress and Problem Areas - 1978 Model Year

Fiat still has had problems meeting the 1978 emission levels at low mileage and has not investigated good NOx reduction techniques. Due to lead time it may be impossible for Fiat to have a competetive system for these emission levels. Especially, difficult to determine is the corporate commitment to meeting post 1977 emission levels. Fiat's continuing work on the Diesel engine is encouraging.

7.3.6 Fuji Heavy Industries (Subaru)

7.3.6.1 Systems to be Used

Systems to be Used - 1977 Model Year

As in past years Fuji in replying on AIR injection and ported EGR for both 49-State and California models. For '77 Fuji has added exhaust port liners and switched from an air pump to an aspirator air injection system similar to the GM Pulsair system. Fuji has led the industry in the utilization of heat conservation techniques for emission control. The exhaust systems of Fuji's vehicles are insulated all the way from the connection with the cylinder head to the muffler. The addition of port liners for 1977 extends this insulation all the way to the exhaust valve. The exhaust port liner installation is shown in Figure Fuji-1.

Fuel economy and emission figures for Fuji's 1977 systems are shown in Table Fuji-1.

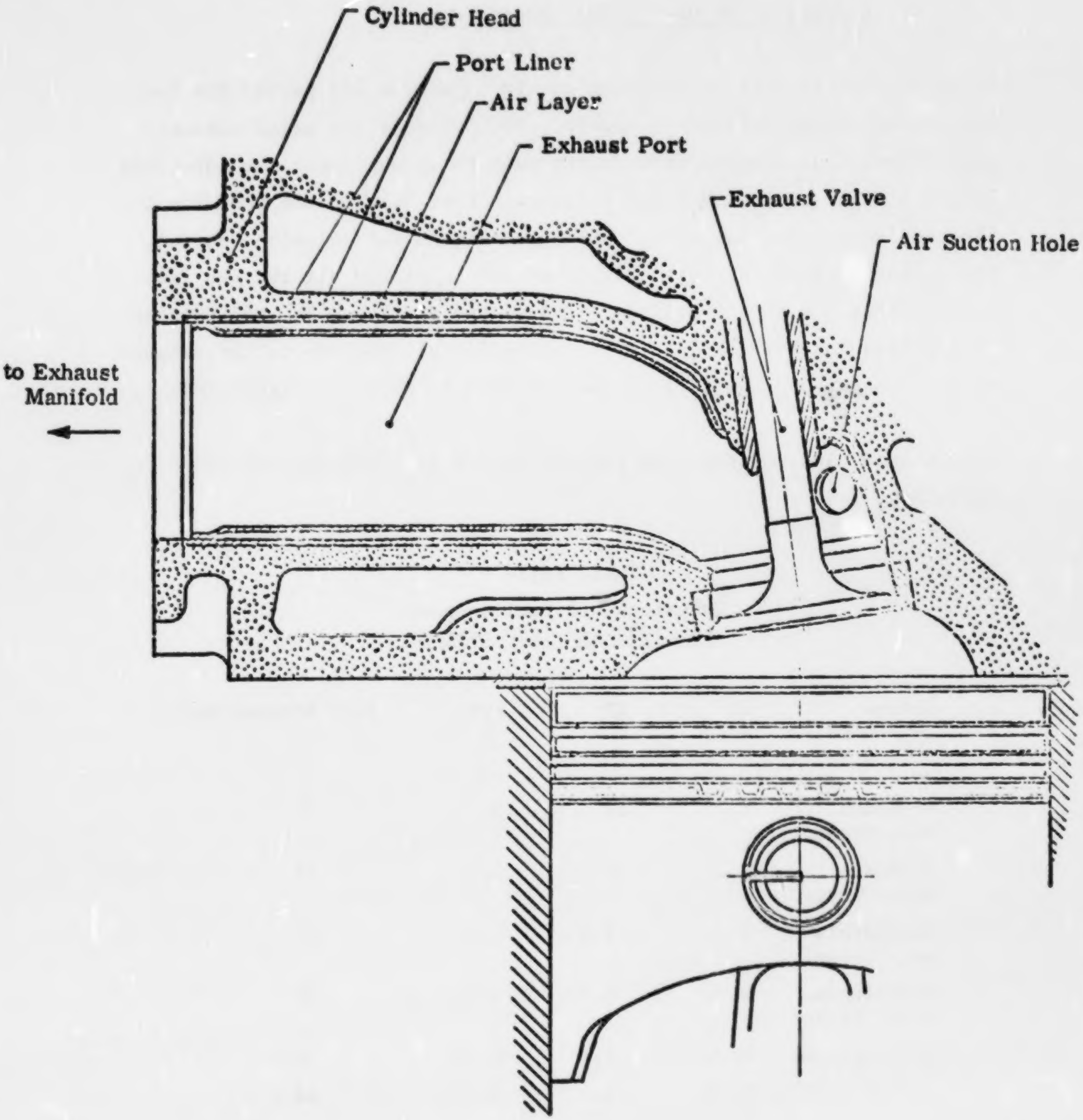
Table Fuji-1

Emissions and Fuel Economy for 1977 and 1978 Systems

System 1977 Models	HC	CO	NOx	Fuel Economy mpg
49-State Man. Trans.	1.1	12	1.7	26
49-State Auto. Trans.	1.2	12	1.8	23
California Man. Trans.	0.3	5.9	1.1	21
California Auto. Trans.	0.35	6.2	1.3	20
1978 Systems	0.30	2.9	0.72	19.2
	0.32	3.1	0.63	18.6

Figure Fuji-1

Exhaust Port Liner


Cylinder Head
Port Liner
Air Layer
Exhaust Port
Exhaust Valve
Air Suction Hole
to Exhaust Manifold

Systems to be Used - 1978 Model Year

Fuji's systems for 1978 are also AIR and EGR. To lower the emissions using these same systems Fuji has resorted to engine recalibration techniques which have significantly compromised fuel economy.. Table Fuji-1 contains data for 1978 systems. The fuel economy penalties shown by the 1978 systems illustrate the fact that for every fixed technology system there is a relationship between fuel economy and emissions. The fuel economy penalties experienced by Fuji at the 1978 emission levels could be reduced or eliminated by augmenting their system with catalytic aftertreatment.

7.3.6.2 Durability Testing Programs

Durability Testing Programs - 1977-1978 Model Year

No durability testing was reported by Fuji.

7.3.6.3 Progress and Problems

Progress and Problems - 1977 Model Year

Fuji's adoption of the exhaust port liners for 1977 completes their exhaust heat conservation package and reconfirms their status as the industry leader in this technology. However, the fuel economy penalties shown for 1977 indicate that Fuji may be pushing this system beyond its optimum fuel economy calibration capability.

Progress and Problems - 1978 Model Year

With the addition of catalytic aftertreatments and proportional EGR, Fuji's systems should be well suited to emission standards down to about the .41 HC, 3.4 CO, 1.0 NOx level. Control to the 0.4 NOx level will probably require either dual catalyst or three way catalyst technology.

7.3.7 Honda

7.3.7.1 Systems to be Used

Systems to be Used - 1977 Model Year

The 1977 Federal Honda systems will be basically the same as the 1976 systems. The 1.2 liter(ℓ) conventional engine will again use only air injection. The 1.5P CVCC will retain exhaust port liners and a lean thermal reactor wth air gap insulation. A 1.6ℓ CVCC engine will be added for use in the heavier 2250 lb. IW sedans. The emission control systems for the 1.6ℓ and 1.5ℓ CVCC engines are nearly identical. The conventional engine will be recalibrated and "auxiliary control devices" will be added. Honda did not say what all the auxiliary devices were; however, they will include a vehicle speed sensor and a spark delay valve. The CVCC engines will incorporate carburetors with improved fuel atomization and manifolds with improved fuel vaporization. Honda anticipates that the fuel economy and emissions of the 1.2 and 1.5ℓ, 2000 lb. vehicles to be as in Table HO-1.

Table HO-1

Honda's 1977 Federal Vehicles*

Vehicle	HC	CO	NOx	MPG_U	MPG_H
1.5ℓ CVCC, 4M	0.8	4.2	1.7	31-32	40-41
1.2ℓ, 4M	1.0	11.5	1.7	26-27	40-41

* From Honda

The expected results for the vehicles with 1.6ℓ engines were not reported. The fuel economy numbers for the similar 1976 certification data vehicles were 31.88 MPG_U and 41.80 MPG_H with the 1.5ℓ engine and 27.55 MPG_U and 40.52 MPG_H with the 1.2ℓ engine. The respective changes in urban fuel economies are +0.3 to -5.9 and -2.0 to -5.6. The respective changes in highway fuel economies are -1.9 to -4.3 and +1.1 to -1.3.

The differences in urban fuel economy between the 1.5ℓ CVCC and the 1.2ℓ conventional engine probably reflect the use of spark retard instead of EGR for NOx control on the conventional engine. Honda stated that the initial cost increases over 1976 would be about $10 for the 1.2ℓ and about $25 for the CVCC. Altitude compensation would cost about $40 and $50 respectively for the bellows controlled systems. Other than a potentially slight increase in fuel cost, no other maintenance cost increases are expected.

The 1977 California models will utilize only the 1.5 ℓ and 1.6ℓ CVCC engines. Their new hardware will be identical to that of the Federal vehicles. Also different calibrations will be used to achieve the expected results in Table HO-2 for the 2000 lb. 1.5ℓ vehicles. Again data for the 1.6ℓ vehicles was not reported. The expected fuel economy numbers for the vehicles with 1.5ℓ engines represent fuel economy losses of 5.9% for MPG_U and 6.7% for MPG_H when compared to the similar 1976 Federal vehicles. The initial cost increase and maintenance cost increases for the California vehicles will be similar to those increases for the Federal CVCC vehicles.

Table HO-2

Honda's 1977 California Vehicles*

Vehicle	HC	CO	NOx	MPG_U	MPG_H
4M	0.3	3.5	1.3	30	39

* From Honda

Systems to be Used - 1978 Model Year and Beyond

Honda reaffirmed their capability to achieve .41 HC, 3.4 CO, 0.4 NOx with the prototype 2.0ℓ engine. No additional testing was reported with the 2.0ℓ engine, but work has started on the 1.5ℓ engine. Improved transient A/F ratio control, improved mixture distribution in the intake manifold, and improved fuel vaporization in the manifold have been reported. Hot start FTP results were reported to be 0.04 HC, 0.83 CO, 0.42 NOx, and 22.8 MPG_U. Cold start NOx was 0.45 and MPG_U was 21.6. This is a 32.2% fuel penalty over the 1976 CVCC. Honda has indicated that their fuel economy goal is to achieve at least 25 MPG_U. To help achieve that goal, Honda is studying many parameters, including the use of EGR and oxidation catalysts on the CVCC. If this program is carefully conducted, the NOx and fuel economy capabilities of the CVCC versus conventional engines may be more fully understood.

Sulfuric acid test results from a CVCC with unspecified calibrations were reported to average 0.34 mg/mi over the sulfate cycle-7 (SC-7). The standard deviation of the five SC-7's was 0.11 mg/mi.

7.3.7.2 Durability Testing Programs

No durability testing was reported in the Honda submission. Previous testing has shown the CVCC to have deterioration factors of less than 1.1 Assuming no great surprises, durability testing will present few problems to Honda at any currently legislated emission level.

7.3.7.3 Progress and Problem Areas

Progress and Problems - 1977 Model Year

Honda is expected to have few problems in certifying Federal and California vehicles in 1977. The biggest question mark is the capability of the new 1.6 liter engine.

The fuel economy of the 1.5 litre CVCC for California shows considerable progress over the 10% fuel economy penalty predicted by Honda last year for the .41 HC, 3.4 CO, 2.0 NOx levels.

Progress and Problems - 1978 Model Year and Beyond

Honda, with its 2.0 liter prototype engine, appears to be the only manufacturer with the capability to achieve the 1978 emission levels (.41 HC, 3.4 CO, 0.4 NOx) in 1978. If the 1.5 litre development program is also successful, it will more firmly entrench Honda as the industry leader in achieving the statutory emission levels. Also if the EGR or oxidation catalyst programs are successful, they could assist in solving the fuel economy problem of the CVCC at these emission levels. Honda has stated that the fuel economy problem becomes most difficult at NOx levels less than 1.0 gm/mi. Driveability was mentioned as a potential problem at the statutory emission levels, but no specific problems were reported.

7.3.8 Mitsubishi

7.3.8.1 Systems to be Used

Systems to be Used - 1977 Model Year

The 1977 Mitsubishi (manufacturers of the Dodge "Celeste" and Plymouth Arrow") system for the 49-States will use increased rate non-proportional EGR, plus a reed valve air injection system which was introduced on their 1976 model year vehicles. (See Figure Mitsubishi-1). The engine configuration, combustion chamber shape, carburetor, choke and choke control, and ignition system will be retained from 1976 model year vehicles. The intake manifold and intake port will have additional coolant circulated past them for better fuel atomization and distribution. No catalysts or thermal reactors will be used.

The 1977 California vehicles will be equipped with an improved carburetor which provides for leaner mixtures through the use of a Mixture Control Valve (MCV). The MVC serves to supply extra air below the throttle during the deceleration mode. The vehicles are also equipped with substantially the same lean thermal reactor with which the 1976 California vehicles were. Air injection will not be used, but exhaust port liners will be. Mitsubishi reported that the spark timing and EGR rates were not finalized yet.

The initial cost increase to the consumer can be found in Table Mitsubishi-1 which was supplied by Mitsubishi. They did not provide any maintance costs for 1977 systems, but they are expected to remain the same as the 1976 model year's.

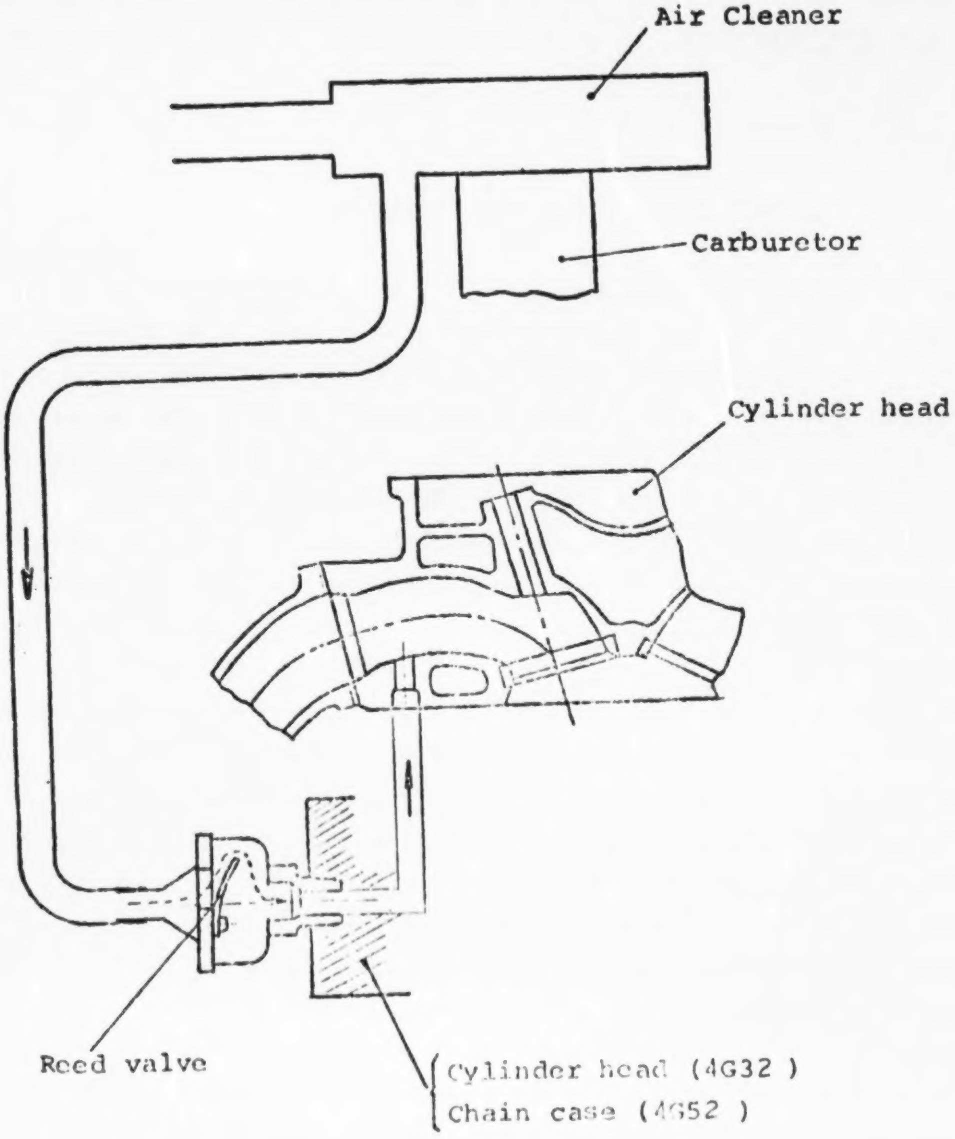

Air Cleaner
Carburetor
Cylinder head
Reed valve
Cylinder head (4G32)
Chain case (4G52)

Figure Mitsubishi 1
Secondary Air Supply System

Table Mitsubishi 1

Estimated First Cost of 1977 Systems (shown as increase over 1976 system)

Configuration	System		Value Added[*1]	Tooling Amortization[*2]	List Price[*3]	Sticker Price[*4]
	49-State	Calif				
Thermal Reactor	—	○	5	1	9.0	**9.4**
Exhaust Port Liner	—	○	2	0.5	3.7	**3.9**
Carburetor	○	○	6	1	10.5	**11.0**
Distributor	○	○	1	0.2	1.8	**1.9**
Intake Manifold	○	○	1	0.8	2.7	**2.8**
End of Line Test	○	○	0.7	0	1.0	**1.1**
Quality Audit Test	○	○	1	0.05	1.6	**1.7**
Others	○	○	3	0.5	5.2	**5.5**

Total 49-State System : $24.0

California System : $37.3

Notes
*1 Value of hardware cost, including material, labor, general overhead costs.
*2 Tooling and equipment amortized over three years.
*3- List price includes dealer margin and profit, which are 22% of sticker price and 10% of list price respectively.
*4 Sticker price includes 5% tax.

Mitsubishi projects that prior to system optimization, their 49-States vehicle would suffer a fuel economy penalty of 3% on the 1975 FTP and 2% on the Highway Fuel Economy Test (HFET). The figures for the California vehicles are a 7% penalty on the FTP and 2% penalty on the HFET. Mitsubishi claims that they are still optimizing their 1977 systems before certification with a target of no loss on the certification test to a 2% gain for the 49-States vehicles.

Systems to be Used - 0.41 HC, 3.4 CO, 1.0 NOx

At the .41 HC, 3.4 CO, 1.0 NOx levels, Mitsubishi indicated that they would abandon their attempts, to be described later, to use the dual catalyst system and replace it with a system package consisting of an oxidation catalyst plus air injection plus EGR. In an effort to define this proposed system, Mitsubishi has developed a 2 diaphragm EGR control valve, (the control parameters are inlet manifold vacuum and port vacuum) to optimize EGR rates to engine speed and load and retain driveability. No emissions levels were reported for this system.

System to be Used - 1978 Model Year

Mitsubishi's first choice system for use in 1978 model year consists of a dual catalytic converter plus EGR plus a secondary air system. They will be using the same basic engine configuration as 1976 with the following exceptions. The carburetor will be calibrated slightly rich to prevent lean excursions and it will encompass high altitude compensation (system unspecified). Mitsubishi is looking at electronic fuel metering but reported no emissions or fuel economy data. The choke will be an oval cam, automatic system which uses a wax filled actuator to prevent converter overheat and quick engine warm-up. The EGR rate will be increased. They plan to use spark retard for both HC and NOx control and are looking at an electronic ignition system which incorporates spark advance control.

The secondary air system consists of a Saginaw type air pump, a split air system to supply some secondary air ahead of the NOx catalyst and the remainder of the air to the oxidation catalyst; an air switching valve to control secondary air during catalyst warm-up and an air control valve to relieve and modulate secondary air. The system can be seen in Figure Mitsubishi-2. An overtemperature protection device which dumps secondary air and lights a warning light will also be incorporated in the 1978 system.

Two methods of improving evaporative control have been tried by Mitsubishi in an attempt to meet the proposed 6g/test standard for the SHED test. The results are listed below in Table Mitsubishi-2.

Table Mitsubishi-2
Evaporative Emissions Proposed 1978

Technique	Diurmal Breathing Loss	Running Loss	Hot Soak Loss	Total Loss
1. Increase purge air flow -				
Mean:	0.7	0	3.9	4.6
Range:	0.5-0.9	0	2.9-4.6	3.4-5.7
2. Increase cannister from 41.4 cu. in. to 58.8 cu. in. -				
Mean:	1.0	0	3.9	4.9
Range:	0.8-1.1	0	2.9-4.6	3.7-5.7

The cost of the proposed 1978 system is detailed in Table Mitsubishi-3, the maintenance cost in Table Mitsubishi-4, and the catalyst replacement costs (unspecified mileage) in Table Mitsubishi-5.

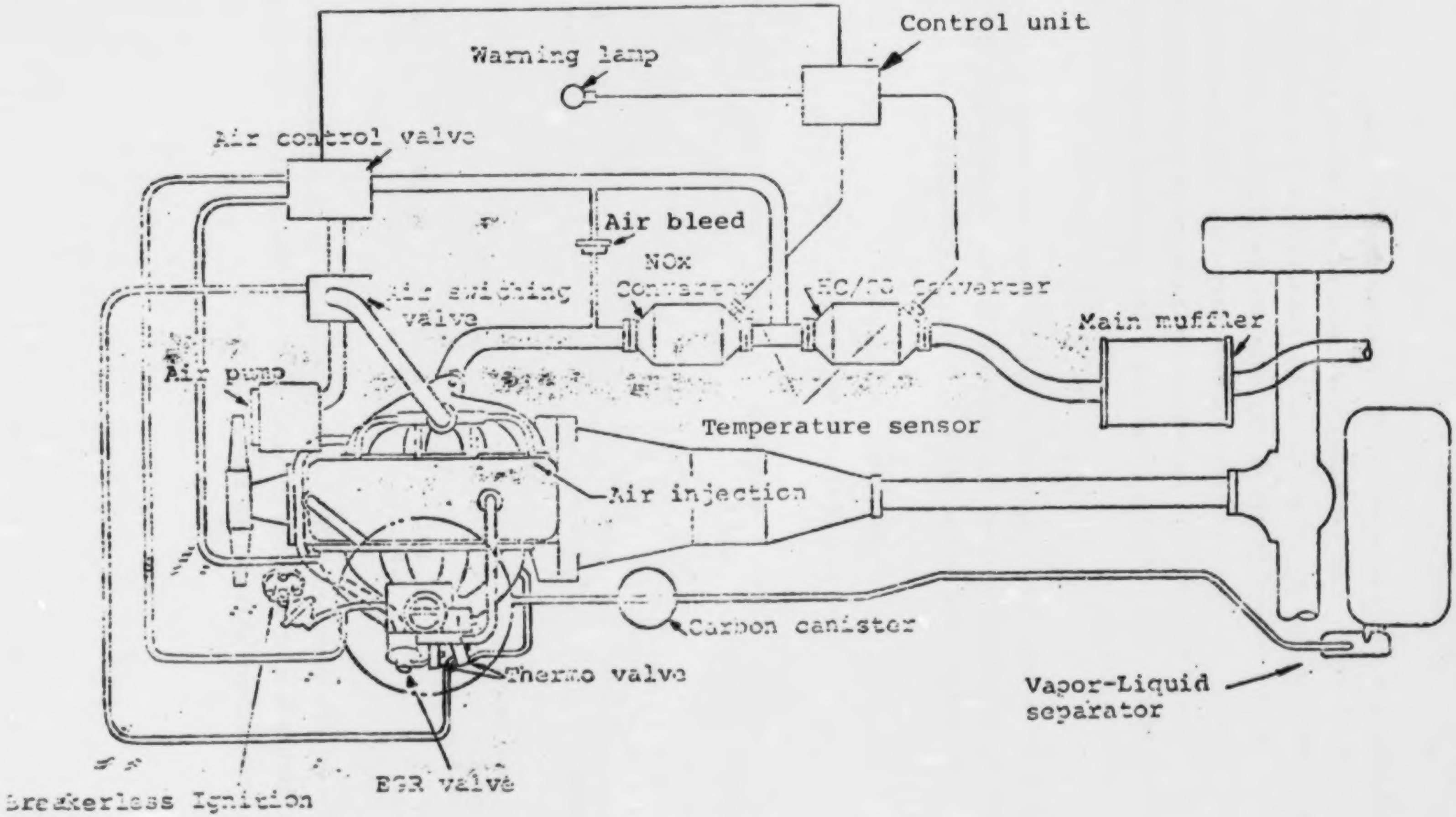

Control unit
Warning lamp
Air control valve
Air bleed
NOx
Converter
HC/CO Converter
Air switching
valve
Main muffler
Air pump
Temperature sensor
Air injection
Carbon canister
Thermo valve
Vapor-Liquid
separator
Breakerless Ignition
EGR valve

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Figure Mitsubishi 2
Schematic Illustration of 1978 System (Dual Converter)

Table Mitsubishi 3
Estimated First Cost of Candidate 1978 System (shown as increase over 1976 system)

Configuration	Value Added*1	Tooling *2 Amortization	List*3 Price	*4 Sticker Price
HC/CO Converter for Pellet	10 ~ 13	1 ~ 2	16.5 ~ 22.5	17.3 ~ 23.6
HC/CO Catalyst	11 ~ 22	1 ~ 2	18.0 ~ 36.0	18.9 ~ 37.8
NO_x Converter for Pellet	10 ~ 13	1 ~ 2	16.5 ~ 22.5	17.3 ~ 23.6
for Monolithic	13 ~ 17	1 ~ 2	21.0 ~ 28.5	22.1 ~ 30.0
NO_x Catalyst for Pellet	36 ~ 72	1 ~ 2	55.5 ~ 111.0	58.3 ~ 116.6
for Monolithic	43 ~ 86	3 ~ 8	69.0 ~ 141.0	72.5 ~ 148.1
Air Injection System	59	1	89.8	94.5
Ignition System	22	1	34.4	36.2
Engine Modification	10	1	16.5	17.3
Evaporative Emission Control System	3	0.1	4.6	4.9
Other Modifications not related with Emission Control	7	0.1	10.6	11.2
Exhaust System Changes	25	0.5	38.3	40.2
Heat Insulation Plates	10 ~ 15	1	16.5 ~ 24.0	17.3 ~ 25.2
System Controls	20	1	31.5	33.1
Assembly Line Changes	0.1	0.5	0.9	0.9
End of Line Changes	2.5	0.05	3.8	4.0
Quality Audit Test	1.5	0.05	2.3	2.4
Others	3	0.5	5.3	5.5
			Total	379.3 ~ 507.0

Notes
*1 Value of hardware cost, including material labor general overhead costs.
*2 Tooling and equipment amortized over three years.
*3 List price includes dealer margin and profit, which are 22% of sticker price and 10% of list price respectively.
*4 Sticker price includes 5% tax.

Table Mitsubishi 4

Estimated Maintenance Cost Penalty by 1978 Emission Control
(Excluding Catalyst Replacement)

Item	Description of Maintenance	Service Interval (Mile)	Labor (hr)	Total* cost ($US)
Air Pump Drive Belt	Check and adjust belt tension, replace if necessary.	Adj: every 15,000 Rep: every 30,000 Belt	0.6 (0.3x2) 0.5 (0.5x1)	12.1 2.5
Air Pump	Check air delivery by flowmeter.	every 30,000	0.2 (0.2x1)	2.2
Emission Check	Measure emission levels at exhaust tail end.	every 15,000	1.5 (0.5x3)	16.5
Air Switching Valve	Check valve motion by vacuum.	every 15,000	1.2 (0.4x3)	13.2
Air Control Valve	ditto			
Spark timing Control	Check timing control in warm phase			
Piping & Wiring, Engine Room Heat Insulation Plates	Visual inspection if there is any damage or irregularity	every 30,000	0.3 (0.3x1)	3.3
Evaporative Control System	Check and clean as required	every 15,000	0.6 (0.2x3)	6.6
Canister	Replace	every 30,000 Canister	0.2 (0.2x1)	2.2 6.6
			Total :	65.2

Table Mitsubishi 5

Catalyst Replacement Cost

($US)

Item \ Catalyst shape	Pelleted	Monolithic
Material Cost :		
Reducing Catalysts	58.3 ~ 116.6	72.5 ~ 148.1
Oxidizing Catalysts	18.9 ~ 37.8	(18.9 ~ 37.8) Pellet
Reducing Container		22.1 ~ 30.0
Gaskets	1.0	1.0
Labor Cost	22.0 (2 hr)	13.2 (1.2 hr)

Total 100.2 ~ 230.1

7.3.8.2 Durability Testing Programs

Durability Testing Programs - 1977 Model Year

Mitsubishi did not submit any durability data from their candidate 1977 systems targeted to meet either the Federal or California standards. Since Mitsubishi had little difficulty in meeting the standards for 1976 and had some California vehicles below .41 HC. The 1976 California vehicles were certified very close to 1.5 NOx and therefore, the systems proposed should allow them to certify in 1977 while allowing room to improve driveability and fuel economy. The systems to be used for the 1977 Federal vehicles should allow them to certify since the 1976 vehicles certified slightly over 2.0 NOx. These vehicles may suffer a slight fuel economy penalty.

Durability Test Programs - 1978 Model Year

Mitsubishi continues to evaluate both base metal and base metal plus noble metal reducing catalyst in monolith or pelleted forms. They are also evaluating platinum and palladium or platinum only pelleted oxidation catalysts. These catalysts are tested in a furnace, on the engine dynamometer, and finally in a vehicle. Other programs are underway on evaluation of the close tolerance fuel metering carburetor, secondary air control, and converter over temperature components of the 1978 system. No data were supplied for the component tests.

Full 1978 system durability testing is being or was conducted on three 2750 pounds IW, 97.5 CID, manual transmission vehicles. The results reported to date are found in Table Mitsubishi-6.

Table Mitsubishi-6

Car 118

Mileage	HC	CO	NOx	F.E.	Comments
0	.31	4.03	.23	24.46	
7,196	.82	8.72	.43		
12,909	1.00	10.55	.63		
22,866	.92	11.32	.50		**Test suspended due to increasing emission levels**
Car 205					
0	.45	2.76	.58	22.09	
666	.36	2.43	.49		
11,452	.27	2.74	.58		
20,609	.29	1.56	.45		
26,219	.30	1.79	.57		
Car 206					
0	.22	2.09	.77	21.94	

7.3.8.3 Progress and Problem Areas

Progress and Problems - 1977 Model Year

Mitsubishi is concerned with improving on or at least maintaining 1976 fuel economy levels while meeting 1977 emission standards. Since, much of the systems proposed for 1977 is now in existance or is carryover from 1976, Mitsubishi should have no trouble meeting the 1977 levels.

Progress and Problems - 1978 Model Year

For 1978 Mitsubishi continues to cite as problems: (1) unsatisfactory performance of NOx catalysts regarding low temperature operation, (2) ammonia formation, (3) poor durability of NOx catalysts, (4) overtemperature problems of catalysts due to engine malfunctions, (5) cost, (6) loss of usable interior space due to size of the catalysts. Completion of the electronic fuel metering carburetor and EGR optimization studies should help alleviate some of the catalyst's problems. Aggressiveness in improving NOx catalysts through component testing could solve the remaining NOx catalyst problems.

7.3.9 Nissan (Datsun)

7.3.9.1 Systems to be Used

Systems to be Used - 1977 Model Year

Nissan will introduce backpressure modulated EGR on both the 49 state and California models for 1977 to meet the lower NOx levels. AIR will be used on all four cylinder engines. The six cylinder engines will have the Bosch L-Jetronic electronic fuel injection (EFI). The 49 state and California models differ principally in the fact that all California vehicles will have catalysts and the 49 state cars will not. The catalysts will have larger volumes than 76 California catalysts. For additional HC control the larger four cylinder engine, 119 cu. in. and the six cylinder engine in the 280Z will have exhaust port liners for all 50 states. The large four is also shifting over to a water heated intake manifold riser instead of an exhaust gas heated one. Table Nissan-1 shows the principal elements of these systems.

Table Nissan-1

Nissan Emission Control Systems

	49 State			Calif. and High Altitude		
Engine Disp. CID	85	119	168	85	119	168
Inertia Weight	2250	2750	3000	2250	2750	3000
System	AIR EGR	AIR EGR EPL*	EFI-EGR EPL*	AIR EGR CAT	AIR EGR CAT* EPL	EFI-EGR CAT* EPL
Ignition	Breaker Pts.	Breaker Pts.	HEI	HEI	HEI	HEI

* Exhaust port liners.

Nissan's high altitude cars will have the California emission control systems. In addition the 85 and 119 cu. in. engines will have a manually switched control which will change the air fuel ratio by switching in an additional air bleed for the secondary circuit. The 168 cu. in. six will have an aeneroid bellows operated on/off switch which will signal the EFI to enlean the mixture at high altitude.

Nissan estimated the cost of the 1977 49 state systems at 10 to 50 dollars over 1976 systems. The California systems were estimated to cost 60 to 100 dollars over 1976 California systems. Nissan did not provide estimates of the fuel economy effects of these systems.

Systems to be Used - 1978 Model Year

Nissan is considering four systems for .41 HC, 3.4 CO, 0.4 NOx level. These are:

1. Three way catalyst system
2. Dual catalyst system
3. Prechamber torch ignition engine
4. Rich-lean reactor system

Two types of three way catalyst systems with feedback control are under study: an EFI system and an electronically controlled computer system EGR would also be used. The carbureted system would have cost advantages over the EFI.

For the dual catalyst system Nissan specifies a monolithic substrate NOx catalyst and proportional EGR. This sytem has been receiving less attention over the past year.

The prechamber engine (NVCC) is a divided chamber stratified charge engine similar to the Honda CVCC. The engine includes EGR and a thermal reactor.

The rich-lean reactor system has two separate induction systems. Half of the cylinders receive an overly rich mixture and the other half receive an overly lean mixture. All cylinders exhaust into a common thermal reactor. NOx emissions are low because the very rich and very lean mixtures will not generate much NOx. The poor driveability of the lean cylinders are offset by the rich mixtures. The high HC and CO of the rich mixture is consumed by the thermal reactor.

7.3.9.2 Durability Testing Programs

Durability Testing Programs - 1977-1978 Model Year

No durability test results were reported for 1977 model year systems. Nissan's highest reported durability test mileage with their three way EFI system is 33,800 miles. At 30,000 miles the emission levels were 0.39 HC, 1.96 CO, 0.37 NOx with a fuel economy of 17.2 mpg. Detailed information on the system and vehicle were not provided. HC and NOx control deteriorated after 30,000 miles.

Nissan has not performed vehicle durability testing on the NVCC engine but low mileage test results were .38 HC, 3.11 CO, 1.01 NOx with urban fuel economy at 21.5 mpg. Nissan did not report details of the system tested.

Nissan accumulated 25,000 miles of vehicle durability testing on a third generation Questor system. A reverter weld failure caused emissions to increase at some point between 20,000 and 25,000 miles and testing was terminated at 25,000 miles. Emissions and fuel economy at 20,000 miles were .21 HC, 3.58 CO, .23 NOx and 17.3 mpg.

No data was reported for the rich-lean system.

7.3.9.3 Progress and Problems

Progress and Problems - 1977 Model Year

Nissan's change from ported EGR to back pressure modulated is encouraging. Also, Nissan's adoption of switch operated high altitude compensation fuel metering systems is a welcome feature. In contrast, most other manufacturers' systems require recalibrations to adjust for altitude changes.

Progress and Problems - 1978 Model Year

Nissan has not made much progress at the 0.4 NOx level. This reflects a low level of development activity. None of the five systems specified by Nissan are being pursued in earnest. The three way system is probably receiving the most attention, but still only one test vehicle was reported.

7.3.10 Peugeot

7.3.10.1 Systems to be Used

Systems to be Used - 1977 Model Year

At the time that this report was written, Peugeot had not submitted any information concerning the status of their gasoline engine programs. They did however submit information regarding the status of their Diesel engine program and the remainder of this section will detail the results of this program.

Peugeot will offer for all 50 states the improved XD2 Diesel engine to power the 504 series vehicles. The engine improvements center on a new fuel injection system to reduce secondary injections. The engine is also bored larger for total engine displacement of 141 cubic inches. The 504 Diesel uses the high swirl Ricardo Comet V prechamber combustion system which is an indirect injection system. The engine uses no emission control techniques other than retarded ignition timing to attain their demonstrated low emission levels. Peugeot reports that the precertification emission levels range from .35 to .6 HC, 1.1 to 1.3 CO, and from 1 to 1.3 NOx. The fuel economy reported for the manual transmission vehicle will be 27 mpg for the urban cycle and 33 mpg for the highway cycle, and 25 and 30 miles per gallon respectively for the automatic transmission vehicles.

Systems to be Used - 1978 Model Year

Peugeot plans to use the same engine for 1978 as will be used in 1977. They are concentrating on improving combustion noise at idle, apparently perceived by Peugeot as being unacceptable to their customers, and lowering the NOx levels to the statutory levels. The prototype system results are shown in Table Peugeot-1.

Table Peugeot-1

Prototype Emission Control System

	HC	CO	NOx	MPGU
Without System	.38	1.1	.95	26
With System	.39	1.8	.52	26

Peugeot contends however, that even with these results the 1978 statutory levels are difficult to meet. They state "Assuming a NOx level between 1.5 to 2 g/mile, it seems to us (Peugeot) that, contrary to some opinion published, it will be difficult to meet only the 0.41 g/mile for HC's with our Ricardo Comet V high swirl chamber engine, owing to the safety margin necessary for taking into account production dispersion and eventual in-time deterioration which may occur during certification tests with durability vehicles." It is significant that Peugeot finds that HC control rather than NOx is the difficult obstacle for the Diesel engine to overcome.

7.3.10.2 Durability Testing Programs

Durability Testing Programs

Peugeot did not report any Diesel engine durability testing at either the 1.5 HC, 15 CO, 2.0 NOx or the .41 HC, 3.4 CO, .4 NOx levels.

7.3.10.3 Progress and Problem Areas

Progress and Problems - 1977 Model Year

Peugeot should not experience any difficulties obtaining certification for the Diesel engine in relation to the 1977 Federal levels. For the

California levels of .41 HC, this engine may line cross although preliminary indications are it will meet the California standards with a slightly improved fuel economy. Peugeot has undertaken a program to characterize unregulated emission, expecially sulfates, from the XD2 engine.

Progress and Problems - 1978 Model Year

While Peugeot feels that .41 HC will be a difficult level to meet, they have instituted investigations into possible solutions to both the HC and NOx problems of the XD2 engine. Other programs include a program to reduce piston/cylinder head distance reducing swirl chamber volume for HC reduction, another to thermally insulate the pre-chamber, another program to reduce secondary injections, and a program for better air utilization of the combustion chamber volume. Preliminary results of the thermally insulated pre-chamber indicate HC levels one-half of present HC levels are achievable.

The status report from Peugeot was incomplete and brief, yet their attempts at heat conservation and NOx reduction from Diesel engines was significant. Peugeot may be able to introduce a Diesel engine which could meet the present 1979 statutory levels for exhaust emissions, with further development.

7.3.11 Porsche

This is the first year that Porsche was asked for a status report. The request was based on the desire for additional information concerning the new Porsche developed stratified charge engine. Porsche replied in the cover letter to their status report that they knew of no emission control system which could comply with the 1978 emission standards. In their opinion, the only possible solutions at those levels were the closed loop catalytic aftertreatment Otto cycle engines, the stratified charge plus EGR plus aftertreatment engine, or the Diesel engine with EGR. Porsche feels that these systems are sure to realize values of 1.0 NOx and for that reason are potential solutions for the value range of .4 to 1.0 NOx. One further alternative was proposed by Porsche at the 1.0 NOx level was that of the Otto cycle engine with a lean mixture and exhaust aftertreatment. Their status report focused on the feedback Otto cycle, the stratified charge engine, and the lean air fuel mixture Otto cycle engine.

While the data presented by Porsche lack sufficient details to assess their various approaches for meeting future standards, data was submitted on preliminary CVS test results, preliminary hardware costs, and fuel economy levels. Little or no durability data was presented for any of the systems proposed for development. No mention was given to what systems will be utilized for either California or 49-states in 1977. No Part I's were submitted. The three systems under active development are outlined below.

Closed-loop plus Oxidation Catalyst System

This system consists of the basic 911 engine modified with an air intake sensor for the K-Jetronic fuel injection system enabling the injection system to remain near the stoichiometric air-fuel ratio; a zirconium oxygen sensor (Lambda sensor), and an oxidation catalyst made by either Degussa or Johnson Matthey. There will be no EGR, AIR, or thermal reactor devices used with this system. The low mileage emission results, fuel economy, and costs can be found in Tables Porsche-1 and Porsche-2. Porsche reports that limited durability testing was done with the system and cold engine driveability was poor. Porsche anticipates that a catalyst change at 25,000 miles will be necessary with this system.

Porsche Stratified Charge Chamber System (SKS)

The difference between the SKS engine and the conventional engine is in the combustion chamber design where the SKS design is not a single chamber but is divided into a main chamber, precombustion area, and ignition chamber. The main combustion chamber is provided with a lean mixture via the usual intake valve. This chamber is situated between the piston top and cylinder head (Figure Porsche-1). The main chamber is connected to a small auxiliary chamber by means of an orifice. The mixture in the auxiliary chamber is enriched by means of an injection nozzle. The auxiliary chamber further consists of a small ignition chamber which serves to assure optimum conditions for the ignition and formation of a stable flame source. The engine presently uses no EGR system or air injection. Both thermal reactors and oxidation catalysts have been used to reduce the high hydrocarbon emissions from this engine.

This engine system is still in the research phase with no vehicle durability reported at this time. The engine is basically a lean mixture main combustion chamber engine which employs a fuel injected, rich mixture to the prechamber to ignite the lean main chamber. This principle has been employed before by other types of stratified charge engines. While Porsche did supply information relative to the optimization of various engine operating and physical parameters, the real worth of the engine will be determined by durability and emissions performance of pre-production vehicles. Porsche confirms that this system has lower power output and poorer performance than their production type engine. The emissions and fuel economy results would tend to bear out lowered performance of the SKS engine.

However, the achievement of relatively low NOx results could indicate the potential for this system when coupled with heat conservation techniques and/or chemical or thermal aftertreatment. Care will have to be exercised to prevent excessive formation of H_2SO_4 since the exhaust of the SKS engine contains 1 to 4% excess oxygen. This system may hold potential for inherently low NOx emissions.

Lean Concept 911 with Catalytic Converter System

This system incorporates into basic 2.7 liter 911 six cylinder engine, increased compression ratio, combustion chamber changes, lean biased K-Jetronic fuel injection and an oxidation catalyst. There is no EGR or AIR injection used.

Porsche has tried various engine parameteric changes on the engine dynamometer to optimize the system for overall lean operation. Vehicular operation indicate both cold and warm driveability problems. They also reported that a catalyst change could be necessary at 25,000 miles.

Because of the limited data and system description submitted by Porsche, it is difficult to assess Porsche's ability to certify for 1977 and 1978. Apparently they tend to favor lean biased engines for control of emissions. Because of the lack of durability data, it is hard to determine if their approaches will be successful. Lean calibration could offer good emission control potential, but only in combination with heat conservation and catalytic treatment. Porsche reported no development work on other techniques, i.e., 3-way, advanced fuel metering, NOx catalysts, and it can only be concluded that Porsche will have a difficult time in reaching .41 HC with lean calibration and oxidation catalysts. Their closed loop system has shown promise at very low mileage and may be used if durability testing is successful.

Table Porsche-1
Low Mileage Emission Results
(g/mile)

System	HC	CO	NOx	MPG_U
Closed loop (Lambda Probe) + Ox. Cat.	.15	4.2	.37	17.3-18.5
Porsche SKS	0.8-2.0	3.0-7.0	.3-.8	13.2-16.6
Lean 911 w/Ox-Cat.	0.7	1.5	1.1	18.4
Lean 911 w/thermal reactor	1.2	6.0	1.2	16.6
1976 Durability Vehicles				
2.7 liter w/TR, EGR, AIR, FI	.30-.79	4.8-8.1	1.1-1.7	14.1-17.5
2.7 liter w/AIR, FI	1.1-1.3	9.0-15.8	2.1-2.8	16.5-19.0

Table Porsche-2
Cost Information

System: Closed loop (lambda probe) plus Ox. Cat

Converter	$100 to 150
Lambda probe	8 to 18
Regulating Electronics	? (Vendor supplied)
Extended K-Jetronic	? (Vendor supplied)

System: Porsche SKS

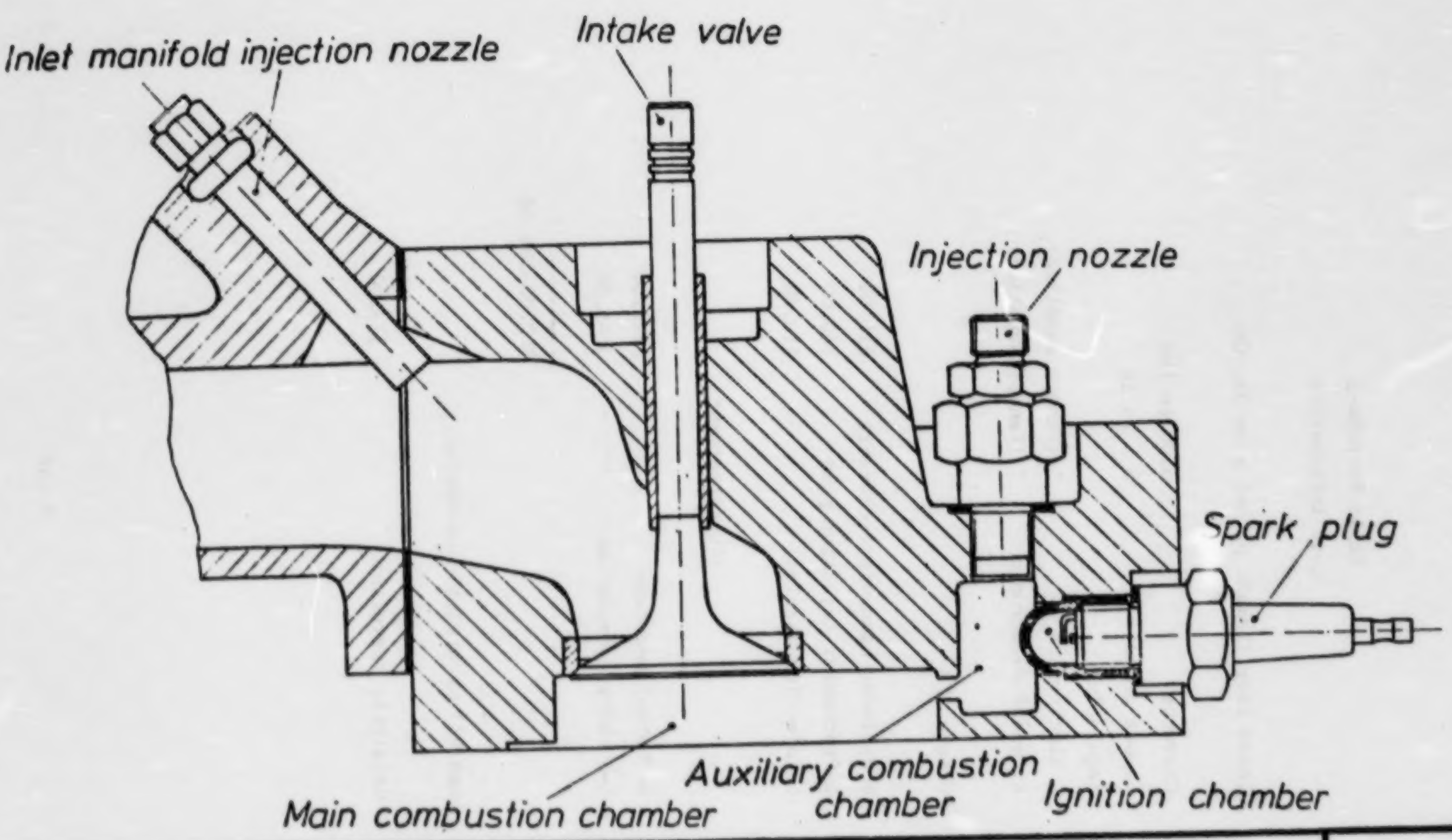
6-cylinder head w/pre-chambers	$16.00
1-Prechamber injection pump	$40.00
6-Injection nozzles	$13.00

Aftertreatment

2-Thermal reactors	$115.00
or 1-Catalytic converter	$ 45.00
	$69.00-184.00

System: Lean 911 w/catalytic converter

Catalytic converter	$73.00


Inlet manifold injection nozzle
Intake valve
Injection nozzle
Spark plug
Auxiliary combustion chamber
Main combustion chamber
Ignition chamber

Porsche SKS-engine principal arrangement

Figure Porsche-1

7.3.12 Renault

7.3.12.1 Systems to be Used

Systems to be Used - 1977 Model Year

Renault's systems for the 1977 model year are described in Table Renault-1.

Table Renault-1
1977 Model Year Systems

Engine Family	Disp. cu. in.	49-State or California	Fuel System	AIR	EGR	Ox. Cat.
843M	100	49s	carb.	yes	no	no
843R	100	49s	carb.	yes	yes	no
843FI	100	49s	EFI*	yes	no	no
810	78	49s	carb.	yes	no	no
843RC	100	Cal.	carb.	yes	yes	yes
810RC	78	Cal.	carb.	yes	yes	yes

* Bosch L-Jetronic

Systems to be Used - 1978 Model Year

An earlier leader in three-way catalyst technology, Renault continues to specify this system for the .41 HC, 3.4 CO, 0.4 NOx level. Two feedback control approaches are being pursued by Renault: EFI and modulated AIR. Table Renault-2 shows emission data for both systems at low mileage.

Table Renault-2

System	HC	CO	NOx	Fuel Econ.
Feedback EFI Englehard TWC 9B three-way cat.	0.31	2.44	0.25	20.3
Feedback modulated AIR three-way cat.	0.3	2.8	0.6	22

7.3.12.2 Durability Testing Program

Durability Testing Programs - 1977-1978 Model Year

No durability testing was reported by Renault for 1977 model year.

Limited durability testing was reported for Renault EFI/three-way catalyst system. Table Renault-3 shows this data.

Table Renault-3

EFI, Engelhard TWC 9B Three-Way Catalyst
No other system details provided

Mileage	HC	CO	NOx	Fuel Econ. (mpg)
0	0.31	2.44	0.25	20.22
4000	0.32	2.57	0.86	21.2
10,000	0.43	3.32	0.97	20.8

7.3.12.3 Progress and Problems

Progress and Problems 1977-1978 Model Year

Renault has not made much progress over this past year at the 0.41 HC, 3.4 CO, 0.4 NOx level. Their work with modulated AIR is of interest because it will likely have a lower first cost than EFI. Not many other manufacturers are pursuing this system.

7.3.13 Rolls-Royce (RR)

7.3.13.1 Systems to be Used

Systems to be Used - 1977 Model Year

It has been RR's practice in previous years to produce only one emission control system specification for both 49-state and California usage. This was due to their relatively low sales volume. For 1977 RR plans to break with that policy because of claimed driveability and fuel economy penalties experienced at the 1977 California levels with their 5500 IW vehicles. The 49-state and California versions will differ in carburetor, ignition and EGR calibrations. In addition, the California system will include air injection. The essential elements of both systems are:

1. Aluminum V-8 engine, 412 cu. in.
2. Twin SU H1F7 carburetors with RR "mixture weakening device".
3. Lucas Opus high energy ignition.
4. AIR, Saginaw pump (California only).
5. Dual Rochester backpressure modulated EGR valves.
6. Oxidation catalysts (Johnson Matthey 23G).
7. PCV and Fvap. systems.

RR had planned to introduce a 444 cu. in. engine for 1977 which would have had lower brake mean effective pressure (bmep) and slipper type pistons to reduce friction. RR feels that both changes would reduce emissions, particularly NOx. An improved combustion chamber shape was to have reduced HC. Unfortunately, lead time delays will prevent introduction in 1977.

The "mixture weakening device" described by RR is supposed to improve high ambient temperature operation. RR is vague as to how this is accomplished but it sounds like a temperature compensation device such as an air bleed.

The EGR system will feature two Rochester integral transducer back-pressure modulated EGR valves operating in parallel.

Each of the two oxidation catalysts has two 6" x 4" oval monolithic blocks. Catalyst volume has increased by 30% for 1977.

RR reports that the fuel economy of their 49-state systems for 1977 will be equivalent to the 50-state 1976 system, 10 mpg urban and 13 mpg non-urban. Fuel economy for 1977 California is predicted to be 8 mpg urban and 11 mpg non-urban.

Systems to be Used 1978 Model Year

RRs first choice system for standards of 1.0 NOx and below will be Bosch K-Jetronic fuel injection with feedback air/fuel ratio control used in conjunction with a three way catalyst. Proportional EGR will be included on this system. RR reports low mileage emission results of .25 HC, 7.0 CO and .75 NOx with such a system.

RR reports work on modulated air injection as an alternative approach to feedback control of the exhaust gas chemistry for three way catalysts. RR is working with Deutsche Vergaser Geselschaft (DVG) on this system which would use a nominally rich engine calibration. The advantage of this system would be lower initial cost because the fuel injection system would not be required. Fuel economy would possibly suffer relative to a fuel injection system because of the rich air fuel calibration.

Another system being considered by RR is the Mobil Low Emission Fuel (LEF) system. This system distills and stores the light fractions of the fuel for use in cold starts. RR reports that the LEF system resulted in a 20% reduction in CO emissions during the cold transient phase (bag 1) of the 75 FTP. The HC effect was not reported. RR indicates that they would not be willing to accept the cost and complexity penalties of this system except as a last resort.

7.3.13.2 Durability Testing

RR did not report any durability test results for their 1977 or 1978 systems.

7.3.13.3 Progress and Problems

Progress and Problems - 1977 Model Year

System selection for 1977 seems to have been well done. As in years past, however, RR has not done much durability testing.

Progress and Problems - 1978 Model Year

RR has made some progress in system selection for 1978. RR received a setback last year when Bosch informed them that their L-Jetronic fuel injection would not be available for the RR V-8 engine. RR has apparently been successful in switching over to the K-Jetronic for use with their three way catalyst systems.

7.3.14 Saab

7.3.14.1 Systems to be Used - 1977 Model Year

Saab's 49-State systems for 1977 will feature Bosch K-Jetronic fuel injection, proportional EGR and a Pulsair type air injection. This system is similar to the 1976 California system except for the change from an air pump to the Pulsair system.

The California system for 1977 will feature the Bosch K-Jetronic fuel injection in conjunction with a three way catalyst and feedback control of the air-fuel ratio. The feedback control will employ an exhaust gas oxygen sensor to maintain a stoichiometric air-fuel ratio for optimum conversion efficiency of HC, CO and NOx. EGR will not be required. Saab reports an expected fuel economy and driveability improvement (versus 76 California systems) for this system.

The Bosch K-Jetronic system is a continuous injection (as opposed to a timed injection) mechanical system. The rate of injection is regulated by an air measuring valve which senses air flow.

Saab estimates that the actual added costs for the above 49-State and California systems are $68 and $194, respectively. The corresponding sticker price increases were estimated to be $92 and $291.

Table Saab-1 compares Saab's reported fuel economies for their 1977 Federal and California systems with their corresponding 1976 system results.

Table Saab-1*

		1976 F.E.		1977 F.E.		% Change	1976 to 1977
System	Trans.	Urban	Highway	Urban	Highway	Urban	Highway
Federal	Man.	23.1	27.8	23	29.6	-0.4	+6.5
Federal	Auto.	19.3	22.1	19.5	26.8	+1.0	+21.3
Calif.	Man.	20.9	24.2	21.5	----	+2.9	----
Calif.	Auto.	16.7	18.6	20.75	22	+24.2	+18.3

*All data supplied by Saab.

Saab reports that work has been stopped on their Low Emission Fuel LEF system which consisted of an on-board distiller for generating and storing the more volatile portions of the fuel to be used in cold starts. Work has also been halted on the electrically heated fuel nozzles which had previously shown impressive HC reductions during cold starts. Saab explained that the complexity of these systems along with some initial problems had caused them to discontinue them. Saab also stated candidly that at the 1.5 NOx level, no supplemental systems were needed.

Systems to be Used - 1978 Model Year

Saab's first choice system for the .41 HC, 3.4 CO, 0.4 NOx level will be the K-Jetronic with feedback controlled air-fuel ratio. Proportional EGR will also be used for additional NOx control. As a second choice Saab would attempt to use a dual catalyst system which would include AIR and proportional EGR.

Saab estimates that the actual added costs of their first and second choice system would be $231 and $254, respectively. The sticker price increases were estimated to be $346 and $381.

Saab indicated that at the .41 HC, 3.4 CO, 1.0 NOx level, their first choice system would be a 3-way catalyst system with feedback control of air fuel ratio and with proportional EGR.

7.3.14.2 Durability Testing - 1977 Model Year

Saab reports durability testing of four three way catalyst systems tailored to the 1977 California emission levels. Seven additional cars are undergoing durability testing to confirm the reliability and durability of catalysts and other emission control hardware.

One of the 1977 California systems has completed 50,000 miles. This vehicle was below the 0.41 HC, 9.0 CO, 1.5 NOx level. The rest of these three way systems have accumulated less than 15,000 miles. One of the systems features AIR and an oxidation catalyst in addition to the three way system.

Durability Testing - 1978 Model Year

Saab did not report any durability testing on systems calibrated for the .41 HC, 3.4 CO, 0.4 NOx level.

7.3.14.3 Progress and Problem Areas

Progress and Problems - 1977 Model Year

Because of their low inertia weight model line and technical foresight, Saab is in an enviable position for meeting the 1977 California standards. Their three way catalyst system with feedback control may show the combined benefits of improved performance, better driveability and increased fuel economy. This system was originally intended for introduction in 1978 but will be introduced earlier because of faster than expected development progress and changed standards. An important factor in Saab's choice of the three way system is the fact that they have already accepted the cost penalty of fuel injection.

Progress and Problems - 1978 Model Year

Saab has not shown any dual catalyst or three way catalyst system data on systems targeted at the .41 HC, 3.4 CO, 0.4 NOx level. Saab has apparently relaxed their efforts at this level because of the uncertainty of this standard.

7.3.15 Toyo Kogyo (Mazda)

7.3.15 Systems to be Used

Systems to be Used - 1977 Model Year

Toyo Kogyo (TK) will continue to market both rotary and reciprocating engines for 1977. TK scored a 31 percent fuel economy improvement (combined city/highway) between the 1975 and 1976 models.

TK will further refine their Lean Combustion System (LCS) for the 1977 rotary engines. This system succeeeded the rich thermal reactor system used on 1975 and earlier model years. For 1977 the LCS will have an improved intake system and thermal reactor. TK reports that the 1977 rotary engine will also feature acceleration enrichment to reduce NOx during accelerations. TK claims that it can meet the 1977 California standards on its rotary engines with practically no fuel economy or performance penalties. They also indicate that the increase in cost is negligible. Aside from system calibrations, the only difference between the 1977 49-State and 1977 California vehicles will be the addition of proportional EGR on the California automatic transmission vehicles. TK indicated that it has been working on the ROSCO (Rotary Stratified Combustion) in parallel with the LCS-II for the 1977. The good fuel economy demonstrated by the LCS-II at 1977 emission levels and higher cost of the ROSCO resulted in the decision to stay with the LCS-II for 1977.

TK will equip their 96.8 cu.-in. reciprocating engine with air injection to meet the 49 State 1977 levels. TK is planning on using proportional EGR and an oxidation catalyst on their 49 State 77.6 reciprocating engine. All reciprocating engines to be sold in California in 1977 will have air injection, oxidation catalyst and proportional EGR. TK estimates a $30 per unit increase for all 1977 reciprocating engines. The fuel economy, performance and driveability will be about the same as in 1976, according to TK.

Systems to be Used - 1978 Model Year

At the .41 HC, 3.4 CO and 0.4 NOx level TK is pursuing the development of two alternative rotary engine systems. One such system is called the ROSCO. The ROSCO employs fuel injection in conjunction with the naturally occurring intake charge swirl to achieve charge stratification. The ROSCO also includes air injection, thermal ractor and proportional EGR. TK reports that they have achieved the 0.4 NOx level "in the laboratory." To overcome the expense of fuel injection TK is developing a system called CISC (Compound Induction Step Control System). CISC is novel system which employs two intake ports, a main port on the side and an auxiliary port on the periphery of the trochoid surface. The auxiliary peripheral port provides the leading side of the combustion chamber with a stratified mixture. Both ports are fed by the same carburetor and apparently receive the same air-fuel ratio. The system also includes air injection, thermal reactor and proportional EGR. TK claims that the CISC system controls both the rate and distribution of EGR flow and this in conjunction with charge stratification achieves stable combustion at leaner air-fuel ratios. This sytem is reportedly in the basic research stage at this time. TK reports that the SCP (Stationary Combustion Process) which showed a lot of promise previously has been dropped because of problems with durability and output. This engine featured a divided construction with a rotating main chamber and a stationary prechamber.

TK estimates that the CISC and ROSCO would suffer a 10 percent fuel economy penalty (compared with 1976 rotary engines) in meeting the .41 HC, 3.4 CO, and 0.4 NOx standard. Performance and driveability are estimated to be relatively unchanged at this emission level. The increase in system cost is estimated to be $250.

For their reciprocating engines at the .41 HC, 3.4 CO, 0.4 NOx level, TK reports that two alternative systems are being developed. These are a dual catalyst system and a system called DISC (Divided Chamber Stratified Charge System). The DISC is similar in principle to the Honda CVCC. The dual catalyst system will employ proportional EGR in addition to the oxidizing and reducing catalysts and air injection. The DISC system features a rich operating prechamber and a lean main chamber. The spark plug ignites the prechamber which in turn provides torch ignition to the main chamber. The carburetor provides the two chambers with their individual air-fuel mixtures via separate intake valves. The main chamber receives proportional EGR.

TK reports that progress has been made in the development of the NOx catalyst for their dual catalyst system. However, no details were furnished regarding its formulation or substrate. The dual catalyst system is estimated by TK to result in a $100 price increase. The fuel economy and performance are reported to be "almost the same" as 1976 models.

The DISC engine is also reported to cost an additional $100 over 1976 engines. TK estimates fuel economy and performance to be "almost the same" but indicates that the displacement would have to be increased to offset the lower specific output (hp/unit of displacement). Driveability is claimed to be equivalent to 1976 models.

7.3.15.2 Durability Testing Program

Durability Testing Programs - 1977 Model Year

TK's durability testing for the 1977 model year is concentrated on the California emission requirements (.41 HC, 9 CO, 1.5 NOx). Five durability cars were reported, four with reciprocating engines and one with a rotary. The reciprocating engines were equipped with an oxidation catalyst, air injection and EGR. The rotary engine was equipped with a thermal reactor and air injection. The cars were reported at mileages ranging from 12,000 to 50,000. One car had exceeded the 1977 California levels. This was a reciprocating engine car which exceeded the NOx level at 50,000 miles.

Durability Testing Programs - 1978 Model Year

TK did not report any durability testing with 1978 rotary engine systems. Seven reciprocating engined cars with 1978 systems were durability tested. These were all apparently equipped with dual catalysts, air injection and EGR (TK's system descriptions were not sufficiently clear). The highest mileage achieved was 30,000. The cars all generally exceeded the .41 HC, 3.4 CO and 0.4 NOx level at fairly low mileage. CO control was particularly lacking.

7.3.15.3 Progress and Problem Areas

Progress and Problem Areas - 1977 Model Year

TK is not expected to encounter serious difficulties in meeting the 1977 California Standards (.41 HC, 9.0 CO, 1.5 NOx). Fuel economy is expected to hold the line or drop slightly at these emission levels. The fact that TK reported only one 1977 California rotary system on durability is a cause for concern but this may be due to a high level of confidence at TK. This confidence probably also explains why no durability testing of 1977 49-State systems (1.5 HC, 15 CO, 2.0 NOx) was reported.

Progress and Problem Areas - 1978 Model Year

TK has a positive attitude toward meeting fuel economy goals and emission requirements. TK's planned systems for 1978 are technically innovative and ambitious. This is particularly true of their rotary engine systems. The ROSCO system appears to be their primary approach to achieving the .41 HC, 3.4 CO, 0.4 NOx level. TK has not reported actual emission data to date but a well optimized stratified charge rotary engine in a low inertia weight classification should do very well. The CISC engine, if it works out, will be a major stride forward in achieving the advantages of stratified charge/lean burn in a rotary engine without incurring the complexity and expense of fuel injection.

TK's reciprocating engine systems for 1978, while not embodying the same degree of technical innovation that their rotaries do, nevertheless, are sound approaches for the .41 HC, 3.4 CO and 0.4 NOx level. The DISC system will need a good deal of optimization, particularly in regard to making the best use of EGR. The dual catalyst systems are showing disappointing durability and CO control at this time.

7.3.16 Toyota

7.3.16.1 Systems to be Used

Systems to be Used - 1977 Model Year

Toyota will use AIR, ported EGR and engine modifications to meet the 1977 49-State standards. The California system for 1977 will consist of engine modifications, AIR, backpressure modulated EGR and a pelleted oxidation catalyst.

Toyota is using exhaust heat conservation techniques on the California systems to promote the after reaction of HC and CO. An exhaust manifold insulating heat shroud and double wall exhaust pipe will be used.

Toyota reported that for reasons of safety they have implemented several measures to avoid catalyst overtemperature conditions. These include an electrically heated choke, and reduction of air injection flow during (1) high speed cruise, (2) on cold start, (3) under heavy load and (4) when the catalytic bed exceeds a predetermined temperature. Toyota did not present data showing the effect of these measures. Other manufacturers have not adopted measures of this type for reasons of safety.

Toyota cost estimates for 1977 and 1978 systems are shown in Table Toyota-1.

Table Toyota-1

Year	System	Cost Increase($)
1977	EM+AIR+EGR EM+AIR+EGR+Oxcat	30-130
1978	P3, P6, P7	200-300

Toyota estimated that the 1977 standards would not result in any fuel economy penalties.

Systems to be Used - 1978 Model Year

Toyota is looking at three alternative systems for the .41 HC, 3.4 CO, 0.4 NOx level. The first system, designated P3, will consist of AIR, proportional EGR, a thermal reactor and an oxidation catalyst. This system will utilize a rich mixture along with EGR to control NOx. The thermal reactor is needed in addition to the oxidation catalyst to control the HC and CO emissions resulting from the rich mixture. The P3 system is judged by Toyota to be less expensive and more durable than the two following systems but it will have a significant fuel economy penalty.

System P6 is a dual catalyst system which includes EGR and a thermal reactor. Toyota has specified the Bosch L-Jetronic fuel injection for this system along with the Gould GEM 68 reduction catalyst. Additional NOx control is obtained through EGR and a rich mixture. The thermal reactor is used, according to Toyota, to warm up the reduction catalyst in addition to controlling HC and CO from the rich mixture. Toyota reports problems with reduction catalyst durability. System P6 should be capable of better NOx control than system P3 but fuel economy may be a problem if Toyota relies on a rich mixture for NOx control.

System P7 is a three way catalyst system. Bosch L-Jetronic electronic fuel injection with feedback is used to closely control the air fuel ratio for simultaneous HC, CO and NOx reduction. EGR would also be provided with this system. The Bosch L-Jetronic and feedback control will make this system more expensive but the fuel economy may be significantly better than the other systems because of its leaner calibration.

Toyota appears to favor system P3 because of its lower initial cost and more proven durability at this time. This system, however, for NOx levels much below 1.0 may result in too high a fuel economy penalty. This coupled with recent industry progress with three way catalyst systems may make Toyota's choice of system P3 look unattractive.

Two new Toyota engine/emission systems, designated TTC-V and TTC-L, have been described recently in the popular press. Inexplicably these engines were not described in Toyota's most recent Status Report to EPA, dated December 1975.

As described in the February 15 issue of Automotive Industries both the TTC-V and TTC-L engines feature a turbulence generation pot (TGP) located between the spark plug and intake valve. These engines are shown in Figure Toyota-1. In the TTC-L system the entire fuel air charge is lean. The spark plug is located at the mouth of TGP and when the plug fires the outrushing of gas from the TGP increases turbulence in the main chamber which reportedly enhances complete combustion and allows more retarded spark timing. The more retarded timing can be used to control NOx. The TTC-L system also features exhaust port liners.

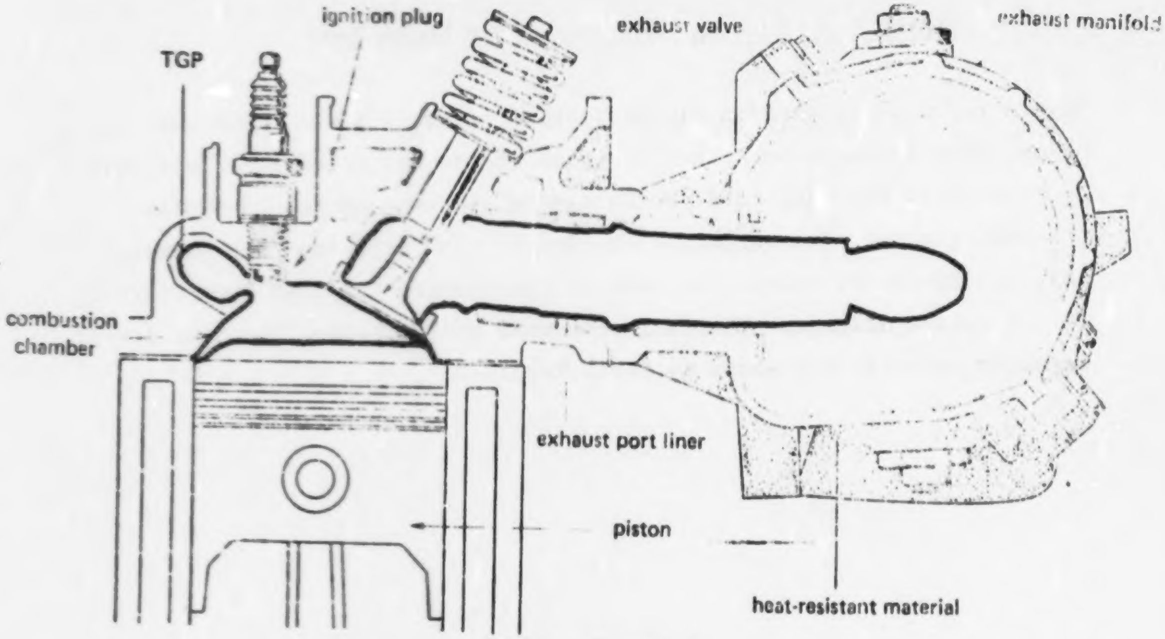


Figure Toyota-1

The TTC-V system is similar to the Honda CVCC system in that it employs an additional inlet valve for the TGP which admits a richer charge than is input to the main chamber. Here again the spark plug ignites the rich chamber which provides a torch ignition to the lean main chamber. It is presumed that the TTC-V engine will run at a leaner overall air/fuel ratio than the TTC-L.

7.3.16.2 Durability Testing Program

Durability Testing - 1977 Model Year

Toyota was well prepared for the 1977 California standard. Toyota has extensive experience at the .41 HC, 3.4 CO, 1.5 NOx level because of an earlier self-imposed goal of achieving this level in 1975. Toyota reported durability test results for two vehicles with 1977 49-state systems and 13 vehicles with 1977 California systems. The emission test data showed Toyota complying with the 1977 standards by reasonable margins with the cars showing consistent results and low deterioration factors.

Durability Testing Programs - 1978 Model Year

Toyota reported testing on eleven systems targeted for 1.0 NOx and below. Five of these were the P7 system (three way catalyst), four were equipped with the dual catalyst P6 system and two had the P3 system (thermal reactor plus oxidation catalyst). The emission results were not too impressive except for some of the systems that had just started to accumulate mileage. The fuel economies and emissions for the lowest emission vehicles are shown in Table Toyota-2.

Table Toyota-

Emissions and Fuel Economy of 1978 Systems
97 cu. in. 2500 IW

System	HC	CO	NOx	Urban(mpg)	High.(mpg)
1976 Model (49s)	1.3	10	2.4	24	31
1977 Dual Cat.	.29	2.38	.23	19.2	24.0
1977 Three Way	.34	1.56	.22	19.3	26.4

7.3.16.3 Progress and Problems

Progress and Problems - 1977 Model Year

Toyota has done a good job of system selection and optimization which should fulfill Toyota's prediction that complying with the 1977 standards will result in no fuel economy penalties.

Progress and Problems - 1978 Model Year

Toyota is making progress on low NOx systems. Toyota appears to be more cost conscious than other manufacturers which will likely mean that system first cost may dictate their ultimate choice. The promise shown by the unreported to EPA TTC-L and TTC-V engines will likely increase Toyota's ability to comply with more stringent standards to a greater degree than suggested in their status report.

7.3.17 Volkswagen (VW)

7.3.17.1 Systems to be Used

Systems to be Used - 1977 Model Year

The Volkswagen emission control systems will vary with the standards (Federal vs. California) and type of engine (air cooled vs. water cooled). For air-cooled engines, VW will use the L-Jetronic fuel injection system (electronic, timed injection system), mechanically controlled EGR, and an improved combustion chamber design. The air-cooled California vehicles will include all of the above plus modified oxidation catalysts. The modification includes the strengthening of the catalyst substrate plus increasing cell structure from 200 cells to 300 cells per square inch. For the carbureted water-cooled engines, VW will use the modified oxidation catalyst, pulsair secondary air injection, and EGR. Basically, the pulsair system utilizes the exhaust gas pulsations, which create momentary exhaust system vacuum to induce air to the area of the exhaust valve seat to oxidize HC and CO.

The water-cooled carbureted California vehicles will have the modified oxidation catalyst, an air pump, and pressure controlled EGR system. On the fuel injected, water-cooled engines the 49-state vehicles will have vacuum amplified EGR systems, the K-Jetronic fuel injection system (a mechanical, continuous injection system); while the California vehicles will also incorporate the modified oxidation catalyst. The EGR system will use a 15,000 mile warning device to signal EGR maintenance.

VW predicts that the fuel economy of their 1977 models will be as good as 1976 vehicles. VW provided no information concerning NOx control at the 1.0 NOx level.

Other Systems

VW continues to conduct investigations into use of the PCI stratified charge engine, a methanol fueled engine, and the Diesel engine. To date, VW has developed and tested both an air-cooled and water-cooled version of a 1600 cc prechamber injection stratified charge engine. A typical schematic of this chamber can be seen in Figure VW-1.

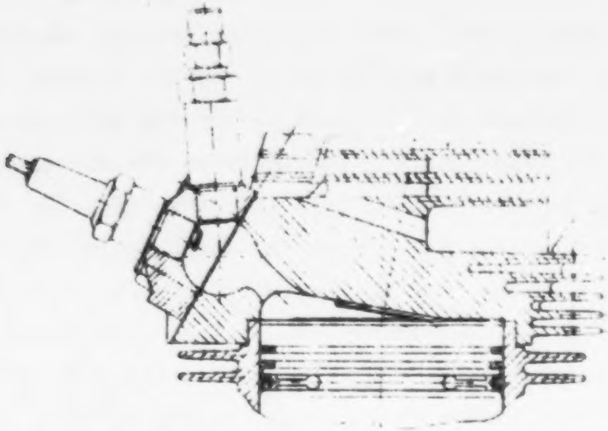


Figure VW-1

The results of emission tests, shown in Table VW-1, indicate that while the air-cooled PCI had inherent low NOx emissions it was high in HC emissions. The water-cooled version using a lean thermal reactor was able to achieve reduced HC emissions but NOx emissions were increased. Fuel economy from these engines remained competitive with present production engines.

On behalf of the West German government, VW continues to do research in the use of methanol for fueling engines. The results from emissions testing is summarized in Table VW-1. Work continues on both of these engines.

The most promising system reported by VW was their light-duty Diesel engine. As seen in Table VW-1, the basic Diesel engine has extremely low HC and CO emissions and NOx levels slightly over 1.0 gram/mile. However, the best data presented by VW indicates that this NOx level could be under 1.0. These results are significant from two aspects. First it shows that at least a small displacement, uncontrolled Diesel engine can achieve levels below 1.0 NOx with good fuel economy. Secondly, this engine could potentially achieve .4 NOx with presently available emission control techniques. These techniques could be as simple as retarded timing and EGR.

Systems to be Used - 1978 Model Year

VW reported three concepts under consideration for model year 1978. For their air-cooled engines they are investigating L-Jetronic fuel injection with an O_2 sensor, 3-way catalyst plus EGR system. For the water-cooled engines, VW is investigating closed loop K-Jetronic fuel injection or carburetion with the 3-way catalyst plus EGR system. The carbureted version will use the O_2 sensor to control air injection rather than the fuel as with the fuel injected engine. In this concept, the engine would run rich and the closed loop sensor would assure that sufficient air was injected ahead of the 3-way catalyst to maintain a stoichiometric mixture necessary for 3-way catalyst operation. VW presented no cost information regarding these concepts but did stipulate that there would be a 10% fuel economy penalty. No estimates were given on system driveability.

7.3.17.2 Durability Testing Programs

Volkswagen's latest status report included a limited amount of precertification durability test data with most of the vehicles having accumulated in excess of 40,000 miles. From the durability data

Table VW-1
Alternative Engines Studied by VW
75-CVS
(gms/mile)

System	IW	HC	CO	NOx	MPG_U	MPG_N
PCI air cooled 1600cc	2250	2.1-2.5	4.4-8.0	.75-.96	22-26	
PCI water cooled 1600cc w/Lean Reactor	2500	.6-.9	3.0-6.0	1.2-1.6	21-24	
Methanol fueled 1600cc		2.5	9.5	1.9		
Diesel Rabbit Ø 1500cc	2250	.19	.98	1.19	37.2*	48.2
	2250	.11	.74	1.12	36.3**	48.4
	2250	-	.69	1.19	39.4***	50.3
"Best" VW Data ØØ	2250	.13	.64	.94	43.0	60.2

* #2 Diesel Fuel
** #1 Diesel Fuel
*** VW type 2D Fuel
Ø EPA Report No. 76-6 AW
ØØ VW Data submission to Report Team, unspecified fuel injection pump.

presented, it could be concluded that VW has potential difficulties in meeting the 49-state standards with their air-cooled engine with high NOx emissions from the lower inertia weight vehicles and high HC emissions from the 3500 IW vehicles. VW should have no problem certifying their water-cooled engines at the 49-state standards. For the air-cooled California vehicles, the data indicates the durability vehicles were not able to meet the .41 HC levels. With the larger vehicles there exists a potential also for high CO values. VW will have to do further work to lower these levels.

On the carbureted, water-cooled engine (Rabbit), the average NOx levels of the durability vehicles exceed 1.5 NOx but there appear to be no problems at low mileage for the fuel injected water-cooled engine families. The durability data presented for model year 1978 emission control concepts indicate that of all the durability vehicles tested so far only one vehicle with K-Jetronic fuel injection approaches .4 NOx levels. However, none of these vehicles used EGR. Further work with these systems is warranted using EGR. Insufficient durability mileage has been accumulated on the 1978 concept. No costs or fuel economy data were supplied on these concepts.

7.3.17.3 Progress and Problem Areas

Progress and Problem - 1977 Model Year

VW continues to conduct research into methods of reducing exhaust emissions while improving fuel economy. Much of their investigation has been applied to their 1977 model year vehicles, including improved catalysts, better Bag 1 HC control, improved air injection components, and improved fuel injection and carburetion. Additional research is aimed at components like the O_2 sensor and three-way catalysts which will be utilized for model year 1978. Much of the research conducted by VW parallels work done by the major domestic manufacturers and indicates essentially the same results. Although, preliminary pre-certification the same results. Although, preliminary pre-certification durability data would indicate that the air-cooled VW engine could potentially have difficulty certifying to the 1977 standards, it is concluded that VW possesses sufficient information and technical knowledge to resolve their difficulties. However, for the California vehicles they may have to request a California waiver for line crossing.

Progress and Problems - 1978 Model Year

VW has now conducted durability testing and basic research on three-way catalyst systems. The limited data to date indicates further work is necessary to improve catalyst and 0_2 sensor durability. Probably insufficient effort has been devoted to this concept to assure its introduction by model year 1978 because of lead time constraints.

7.3.18 Volvo

7.3.18.1 Systems to be Used

Systems to be Used - 1977 Model Year

Volvo markets two engine models, a 130 cu. in. four cylinder and a 163 cu. in. V-6. For their 1977 49-State cars, Volvo's first choice systems for both the four cylinder and the V-6 will include the Bosch K Jetronic continuous fuel injection system, breakerless ignition, an oxidation catalyst and proportional EGR (venturi vacuum amplified). Their second choice system is identical except for the addition of air injection for better HC and CO control.

For the 1977 California levels Volvo's first choice system for their four cylinder will be a three way catalyst system with feedback control of air-fuel ratio. The Bosch K Jetronic will be modified with a vacuum actuated servo mechanism which adjusts the air-fuel ratio in response to an exhaust gas oxygen sensor. In case this system is not sufficiently perfected in time for certification, Volvo will use a more conventional system consisting of a recalibrated 49-state system. Their V-6 engine will have a recalibrated 49-state system for California in 1977. The V-6 engine presents some installation complications for the three way system which caused Volvo to delay its transition to the three way system.

Systems to be Used - 1978 Model Year

For both the four cylinder and V-6 engines at the .41 HC, 3.4 CO, 0.4 NOx level, Volvo will recalibrate their 1977 California three way system and add proportional EGR. As a second choice, Volvo has selected a dual catalyst system. Table Volvo-1 shows the control systems, fuel economies and costs as estimated by Volvo for the various emission levels.

Table Volvo-1

Emission Level			Control System	Price Increase($)	Fuel Economy Percent Change from 1976
HC	CO	NOx			
1.5	15	3.1	Air, Ox cat. ported EGR	136	0
1.5	15	2.0	AIR, Ox cat. prop. EGR	192	+4
.41	9	1.5	1) Three way 2) AIR, Ox cat prop. EGR	272 265	+5 -2
.41	3.4	0.4	1) Three way, Prop. EGR, Mod. spark advance 2) Dual Cat. AIR Prop. EGR	422	0

Other Systems

Volvo has previously reported work on a combined lean choke and acceleration enrichment system. This system was tailored to a three way catalyst with feedback system and held promise of holding down cold start enrichment to the bare minimum. The theory behind this concept

was to augment the lean choke curve on the Bosch K Jetronic fuel injection with a short duration pulse of increased fuel flow. This system worked satisfactorily in early CVS testing but Volvo claims that low temperature testing revealed unacceptable driveability. Volvo is doing further work to refine the system.

7.3.18.2 Durability Testing

Durability Testing - 1977 Model Year

Volvo reports durability testing on 15 vehicles equipped with three way catalysts and feedback air-fuel ratio control. Five of these have completed 50,000 miles. The principal purpose of this testing is the evaluation of the available catalyst formulations, feedback control system modifications and oxygen sensors. Emission results showed mixed results with HC control being a problem, along with oxygen sensor durability. None of the cars that completed 50,000 miles remained below their emission targets for the full mileage. Durability testing was also reported for the customary emission control systems.

Volvo is also starting a 20 car fleet of three way system vehicles on customer usage type mileage.

Durability Testing - 1978 Model Year

Volvo did not report any durability test results for systems calibrated to the .41 HC, 3.4 CO, 0.4 NOx level.

7.3.18.3 Progress and Problems

Progress and Problems - 1977 Model Year

Volvo remains one of the leaders in three way catalyst technology. Inspite of their relatively low volume of U.S. sales, Volvo has mounted a major development and testing program for the three way system which holds good promise of achieving stable catalyst conversion efficiencies

and sensor durability. As insurance, however, Volvo is also well backed up with recalibrated 1976 systems in case the three way is not workable for 1977.

Progress and Problems - 1978 Model Year

Aside from laying out the general approaches envisioned at the .41 HC, 3.4 CO, 0.4 NOx level, Volvo has accomplished little in the way of development progress. This is probably attributable to the uncertainty surrounding this standard.

Appendix 1

A copy of the letter sent to the manufacturers, along with the outline of the information requested, is shown below:

Dear Sir:

As part of its continuing overview of the industry's efforts, and to implement sections 202(b)(4) and 202(b)(5) of the Clean Air Act, as amended, the Environmental Protection Agency needs current information on efforts by automobile manufacturers to meet the 1977, 1978, and future model year light duty motor vehicle emission standards. Accordingly, pursuant to section 307(a)(1) of the Clean Air Act, you are requested to provide us with information regarding your development status and progress toward meeting these standards. This information is similar to and will update the information which your company has provided in the past in response to similar requests.

I had mentioned this request for information in my letter to you of August 5, 1975 in which EPA requested information about sulfuric acid emission control technology.

The desired information, which is described in the enclosed outline, is divided into five main areas: a) information describing the design of your emission control system, b) information describing your test and development programs, c) emission data covering both regulated and non-regulated pollutants, d) fuel economy, and e) cost information. Additionally, there may be specific questions that apply only to your company, attached to the enclosed outline.

The information provided by your company should, in general, follow the enclosed outline. You may limit the information supplied in response to this request to that information which has not previously been supplied to EPA. However, if portions of the desired information have already been supplied to EPA and you wish not to resubmit these, please indicate the appropriate documents by specific reference.

Three copies of your response should be submitted to EPA no later than November 1, 1975. Responses should be addressed to:

Director, Emission Control Technology Division
Attention: Status Report Team
Environmental Protection Agency
Motor Vehicle Emission Laboratory
2565 Plymouth Road
Ann Arbor, Michigan 48105, USA

We realize that much of the information requested on the 1977 model year systems may be included in your company's 1977 Part I certification application. That document, however, is needed by the Certification Branch, and cannot be made as available to the Status Report Team as is necessary for the purpose of this report. Therefore, we request that you include two copies of that document with your response to this letter, in addition to the other information requested in the outline, and that wherever appropriate in responding to the outline you reference the relevant sections of your Part I application for the 1977 model year.

Questions concerning the data requested should be addressed to Mr. John DeKany, Director of the Emission Control Technology Division, whose Division has primary responsibility within EPA for acquiring and analyzing data on the status of technology for automotive emission control. Also, staff from that Division may contact you for additional information or explanations, and such requests should be deemed by you as an integral part of the request for data made by this letter.

Your cooperation in ensuring that the Environmental Protection Agency receives clear, detailed, and understandable information describing the efforts of your company in the design, development and testing of 1977, 1978, and future model year emission control systems will contribute materially to assuring a sound decisionmaking process related to the implementation of the Clean Air Act.

Sincerely yours,

Roger Strelow
Assistant Administrator
for Air and Waste Management

Enclosure

OUTLINE FOR EMISSION CONTROL STATUS REPORT

The following outline should be followed in submitting the requested information. Any information not identified in the outline or the discussion of the outline that you feel is necessary for an accurate and complete description of the emission control technical effort of your company may also be included.

I. Emission Control Systems

   A. Identification and description of the entire emission control system
   B. Discussion of system optimization
   C. Description of system operation

II. Development and Testing Program

   A. Description of test program and organization
   B. Test program basis and rationale
   C. Test vehicle description
   D. Test program status

III. Experimental Data

   A. Vehicle data
   B. Non-vehicle data

IV. Fuel Economy

   A. On the 1975 test procedure ("city" cycle) and on the EPA non-metropolitan ("highway") cycle
   B. Fuel economy on other cycles

V. Cost Information

   A. First Cost
   B. Operating Cost

VI. Confidentiality of Trade Secret Information

DISCUSSION OF OUTLINE

Please provide the following information for the applicable model years and standards discussed below:

	Model Year	HC	CO	NOx
1.	1977 49-states	1.5	15.0	2.0
	1977 California	0.41	9.0	1.5
2.	1978 50-states	.41	3.4	0.4

A separate discussion of the outline topics for each of the sets is requested.

The Agency realizes that no Federally legislated standard for NOx exists between 2.0 NOx and 0.4 NOx. However, because of interest in the NOx level of 1.0 grams per mile, the Agency wishes to receive from your company a discussion of the 0.41 HC, 3.4 CO, 1.0 NOx levels in conjunction with your response concerning your development programs targeted toward 0.41 HC, 3.4 CO, 0.4 NOx.

Answers to the following questions should be included in the discussion of the 0.41 HC, 3.4 CO, 0.4 NOx development programs.

1. Which systems, currently under consideration for 0.4 NOx would also be considered attractive at 1.0 NOx? Please give the reasons.

2. Which systems currently under consideration for 0.4 NOx would not be considered attractive at 1.0 NOx? Please give your reasons.

3. Which systems not under consideration for 0.4 NOx would become candidates at 1.0 NOx? Again, please give your reasons.

4. What impacts, other than system choice, do you consider would be attendant with the change to 1.0 NOx from 0.4 NOx? Consider especially fuel economy, first cost, and maintenance cost.

DISCUSSION OF OUTLINE

Please provide the following information for the applicable model years and standards discussed below:

	Model Year	HC	CO	NOx
1.	1977 49-states	1.5	15.0	2.0
	1977 California	0.41	9.0	1.5
2.	1978 50-states	.41	3.4	0.4

A separate discussion of the outline topics for each of the sets is requested.

The Agency realizes that no Federally legislated standard for NOx exists between 2.0 NOx and 0.4 NOx. However, because of interest in the NOx level of 1.0 grams per mile, the Agency wishes to receive from your company a discussion of the 0.41 HC, 3.4 CO, 1.0 NOx levels in conjunction with your response concerning your development programs targeted toward 0.41 HC, 3.4 CO, 0.4 NOx.

Answers to the following questions should be included in the discussion of the 0.41 HC, 3.4 CO, 0.4 NOx development programs.

1. Which systems, currently under consideration for 0.4 NOx would also be considered attractive at 1.0 NOx? Please give the reasons.

2. Which systems currently under consideration for 0.4 NOx would not be considered attractive at 1.0 NOx? Please give your reasons.

3. Which systems not under consideration for 0.4 NOx would become candidates at 1.0 NOx? Again, please give your reasons.

4. What impacts, other than system choice, do you consider would be attendant with the change to 1.0 NOx from 0.4 NOx? Consider especially fuel economy, first cost, and maintenance cost.

I. EMISSION CONTROL SYSTEMS

You may recall that last year the Agency specifically requested information about your efforts in the area of Advanced HC Control Techniques, and that that section is not included in this year's outline. This does not mean that the Agency is not interested in Advanced HC Control Techniques, however. It was clear from last year's responses that most manufacturers felt that discussion of such systems or techniques more properly belonged in the section discussing the entire emission control system. Accordingly, you are requested to provide the information discussed below for Advanced HC Control Techniques in conjunction with your identification description of the entire emission control system. Such techniques include but are not limited to: improved combustion chamber design; optimization or air injection systems (including feedback control); improved quick-heat intake manifolds; start catalysts; improved catalysts; cold-start HC traps, on-board fuel preparation systems, such as a still for producing light ends for starting; and special catalyst light-off techniques.

A. Identification and Description of the Engine Emission Control System

This should include both a generic and specific description of each system (first choice and all backup systems) under consideration for the model year under discussion. If any feature of the emission control system differs between model lines it should be treated as a different system. An example might be the emission control systems for a 2000 lb. IW vehicle as contrasted to the emission control system for a 5000 lb. IW vehicle. An example of a generic model year 1976 emission control system is engine modifications, EGR, and an oxidation catalyst. The detailed description should include enough information about the system to distinguish it from other systems in the same generic category. The description should be accompanied by engineering drawings and pictures when appropriate to more fully identify and describe the system or subsystem. At least the following topics should be discussed and fully identified.

1. Engine type - reciprocating 4-stroke, rotary, etc.

2. Engine modifications - compression ratio, combustion chamber shape, valve timing, bore/stroke ratio, spark plug location, etc.

3. Intake system - detailed description of carburetor(s), fuel injection system, choke and choke control, intake manifold and intake port.

4. Exhaust port and manifold description.

5. Ignition system.

6. EGR system - flow rate as a function of engine speed and load, type of control, take-off location, introduction location, type of cooling (if cooled).

7. Air injection - type of pump, supplier, flow rate vs. engine speed and load, modulation and switching control, location and type of air injection nozzles.

8. Thermal reactor - type (lean/rich), configuration, materials, internal flow geometry.

9. Catalysts - type (reducing/oxidizing), active material (general) class or specific, (if known), loading and total weight of each catalyst material and the total in troy ounces per vehicle, substrate structure type (monolith/pellet), substrate composition washcoat composition, total surface area of the washcoat, surface area per displacement of the washcoat, catalyst location, shape and size, geometry, manufacturer and manufacturer's identification number, nominal space velocity and space velocity range.

10. Evaporative emission control system - general description including degree of use of air cleaner/horn as storage volume, type of storage material, volume of storage material, purge and fill tube routing, purge rate, purge controls, and location and design of purge vapor inlet to the air cleaner/carburetor/exhaust system.

B. Discussion of System Optimization

1. This should include a discussion of the design constraints within which each system was optimized for emissions. Examples of such constraints are, fuel economy, safety, cost, driveability, packaging, maintenance, and performance. Quantitative values should be identified for all of the constraints for which your company has determined such quantitative values. Others should be discussed in the manner in which they were set down for the design engineer.

2. This should provide a discussion of all designs that were not successful in surviving the optimization studies that your company performed, giving the criteria by which they failed.

3. Of the systems that are under consideration for the model year being discussed, identify and explain any trade-offs that have been made within the emission control system. Quantify any examples by including design calculations or engineering reports. An example might be catalyst location, where one emission control related trade-off could be the trade-off between a location close to the exhaust port for fast light-off vs. a more remote location that might provide a longer catalyst life. Another tradeoff might be the interaction between increased mechanical octane (to permit operation on 91 RON fuel at higher compression ratio, for improved fuel economy) and the desire to reduce engine-out HC emissions.

4. The Agency considers that there are two primary areas in which the design and/or operation of the emission control system might influence vehicle safety. These areas refer to fuel system/evaporative emission control design and/or operation and catalyst temperature. To allow the Agency to understand the emissions/safety interrelationships, please answer the following questions.

a. At what stage in the research, design, development and testing phase are the safety aspects of emission control systems and/or devices considered?

b. What sort of testing and analysis is performed to evaluate the designs for their likely safety-related performance? Please give specific examples.

c. List and discuss all changes made to the exhaust and evaporative emission control systems developed by your company, that were made because of safety considerations. Include both changes made during the development process and changes made after the systems were in production.

5. The discussion of system optimization should also include discussion of evaporative emission control, with special emphasis on the interactions between the evaporative and exhaust emission control system. The Agency knows that there can be interactions between the evaporative and exhaust emission control systems, and considers the subject area to be a more important one for the future, especially at low HC and CO levels with more effective evaporative emission control systems. More effective evaporative emission control systems may be required for the 1978 California 6 gram SHED standard, and as you know, EPA has also indicated its desire to use the SHED procedure in the future.

Therefore, you are requested to discuss the optimization of the entire emission control system, including the evaporative emission control system. The discussion shall include listing of all tests run to determine the interactions and a listing of all test results, including all SHED tests run on your vehicles with developmental emission control systems.

6. Discuss any trade-offs or emission control system modifications that may have been made to improve sulfuric acid emissions.

C. Description of System Operation

1. The sequence of operations of the entire emission control system during the 1975 Federal Test Procedure should be discussed in detail, with special attention given to those parameters which vary during the cycle, for example, spark timing, the choke position, air injection (if modulated or switched), EGR flow rate, and evaporative system purge.

As backup information to the general description of how the emission control system works during the emission test, please provide the following quantitative information as a function of time during the 1975 CVS-CH test, starting with "key-on".

a. engine exhaust flow rate in SCFM

b. engine air flow rate in SCFM

c. spark timing-vacuum and centrifugal separately, plus total spark timing.

d. exhaust gas recirculation rate as a percentage of fresh inlet air flow.

e. air injection flow rate into the exhaust manifold or pipe.

f. nominal engine air/fuel ratio, as determined upstream of any aftertreatment device, for example a catalyst or thermal reactor.

g. exhaust gas temperature before and after any aftertreatment device.

h. catalyst temperature (if a catalyst is used). The information may be presented graphically, for example, superimposed on the speed vs. time trace of the emission test, or in tabular form, on a second-by-second basis.

i. exhaust gas O_2 level before and after any aftertreatment device.

j. evaporative system condition and purge rate.

The above information is requested for each engine family/emission control system. If more than one control system behaves the same during the test, that may be noted. However, control systems with markedly different characteristics; i.e., proportional vs. non-proportional EGR or different carburetor metering principles, should not be deleted.

2. The way in which the system operates under the following other conditions should be discussed; the emissions under such conditions should be quantified in III-A below.

a. Operation in low (less than 60 degrees F) or high (greater than 86 degrees F) temperature ambient conditions.

b. Operation under conditions of speed and/or load which do not occur during the 1975 Federal Test Procedure.

c. Operation at low barometric pressure, for example, at elevations significantly higher than sea level.

II. DEVELOPMENT AND TESTING PROGRAM

A. Description of Test Programs

1. This should include a general description of the type of laboratory or bench scale testing carried out on emission control subsystems or components.

2. This should include a description of any catalyst screening tests and the basis for selecting/rejecting catalysts.

3. This should include a discussion of any tests made for optimization purposes described in I-B above, a general description of the variables that were changed, the range over which they were varied, and the inferences drawn from the system optimization tests.

B. Test Program Basis and Rationale

1. This should include general discussion of the use of vehicles for component testing and trade-off studies, especially as it affects system optimization. Distinction should be made between vehicles used for component testing vs. complete system tests.

2. This should include a complete description of all vehicle emission test programs for the model year under discussion, including the number and type of vehicles, the reasons for choosing the vehicle mix, the mileage accumulation schedule for each vehicle and the number of emission tests at each mileage point.

C. Test Vehicle Description

This should include an identification of the vehicle; car line,test weight, transmission type, axle ratio and an identification of the emission control system as outlined in I-A.

D. Test Program Status

This should include a discussion of the current status of each emission durability vehicle and a comparison of its status with respect to the original planning. Significant problem areas, if they exist, should be identified.

III. EXPERIMENTAL DATA

A. Vehicle Data

1. Include 1975 FTP data on all durability fleet vehicles described in II-B above.

2. Include a description of the reasons for any vehicle not completing the full scheduled durability mileage.

3. Include a discussion of the driveability and performance of the test vehicles, again with quantitative data and with quantitative comparisons to current model year vehicles.

B. Non-Vehicle Data

1. This should include the results from any catalyst screening tests, with a description of test methodology, and must include the test results from the catalysts that were selected for the durability vehicles.

2. Include any other non-vehicle data considered important, such as engine dynamometer studies on the effect of fuel contaminants on catalyst durability.

C. Unregulated Pollutant Emissions

All data developed by your company on the emissions of platinum, other particulates, and other unregulated pollutants emitted from future emission control systems, and from current vehicles, should be presented. This includes all data from bench, engine dynamometer and vehicle tests.

A full description of the measurement methods (driving schedule, sampling and analytical techniques) used to obtain the above information should be provided.

IV. FUEL ECONOMY'

A. On the 1975 Test Procedure

Provide the weighted 1975 fuel economy for all tests run on advanced emission control systems. Use the following formulae for fuel economy and fuel consumption:

$$\text{fuel economy in miles per gallon} = \frac{2423}{.866\ HC + .429\ CO + .272\ CO_2}$$

Where HC, CO and CO_2 are the weighted exhaust constituents in grams per mile for the entire 1975 test, with the same .43/.57 cold start/ hot start weighting as applied to the HC and CO values for the 1975 test also applied to the CO_2 values.

$$\text{fuel consumption in litres per 100 kilometres} = \frac{235.2}{mpg}$$

B. On the EPA Non-metropolitan Driving Cycle

Provide the fuel economy and fuel consumption data for all tests run using the EPA Non-metropolitan ("Highway") Driving Cycle. Use the formulae in IV-A, above except that the HC, CO and CO_2 values in grams per mile are, of course, not weighted.

C. Fuel Economy on Other Cycles

If you possess fuel economy data using a different procedure, you may also submit that data. The test procedure should be specified in detail, if that information has not been previously submitted to EPA.

V. COST INFORMATION

A. First Cost

1. The cost breakdown should be in the same form as that used by the National Academy of Sciences Committee on Motor Vehicle Emissions in

Table 5-2 of their February 15, 1973, report to the EPA. This should also be specific as to what fraction of the various product lines will require specific devices.

B. Operating Costs

This should include expected extra costs to the customer over the vehicle lifetime (assume 50,000 miles) due to:

1. Fuel and lubricant cost, specifying the miles per gallon fuel economy assumed for each engine family and a comparison to 1974 model year vehicles of the same class.

2. Maintenance cost other than catalyst replacement. Such estimates should break out parts and labor cost separately, providing the ratios of parts cost for OEM vs. replacement cost. The estimate should also indicate the expected level of required maintenance on each major emission control component which results in such costs.

3. Catalyst replacement cost. This estimate should separate labor and material costs and should give the estimated life of the catalyst. Material costs should break out catalyst and container costs.

VI CONFIDENTIALITY OF TRADE SECRET INFORMATION

A. Information submitted in response to the request which accompanies this outline will be deemed to have been obtained pursuant to section 307(a)(1) of the Clean Air Act.

B. This means that only information which "...would divulge trade secrets or secret processes" will be kept in confidence. (Even this information will not be kept confidential in two situations: (1) when the information is emission data, or (2) if and when the information becomes "relevant" to any proceeding under the Act. See, in particular, paragraph D.) In order to assure that such information will be kept confidential prior to any proceeding, you must clearly identify the data you regard as likely to "...divulge trade secrets or secret processes" if disclosed, and you must present information to substantiate such claims. Such claims and supporting information must be submitted at the time of submission of the requested information or such claims will be deemed to be waived.

C. If the Administrator determines that a satisfactory showing has not been made that the information would disclose trade secrets or secret processes, you will be notified by certified mail. No sooner than 30 days following the mailing of such notice, any information with respect to which trade secret status has not been established will be placed in a public docket. Any information as to which the Administrator determines that a, satisfactory showing has been made will be held confidential in the period prior to commencement of any suspension proceeding.

D. As in the case of the previous suspension proceeding, if any trade secret information becomes pertinent to the issues raised in a new proceeding on an application for suspension, it may be disclosed by the Administrator. In order to retain confidential treatment of such information, you must show to the satisfaction of the Administrator, that non-disclosure of such information is justified by "...exceptional considerations", as that phrase was defined in the course of the previous suspension proceeding. The showing that must be made is that the information is of such slight probative value in resolving the issue being considered by comparison to the harm likely to result from disclosure that public release of the information is not justified. If the Administrator determines that a satisfactory showing has not been made, you will be notified by certified mail. No sooner than 10 days following the mailing of such notice and telephone notice to a representative of your General Counsel's office, such information will be placed in a public docket. Any information as to which the Administrator determines that a satisfactory showing has been made will be held confidential and will not be considered by the Administrator in deciding whether to grant or deny a pending application for suspension.

The date of the responses received from the respective manufacturers is shown in Table A1-1.

In general, most of the status reports were received later than the requested date, and not one status report fully complied with all of the details of the outline, as has been the case in the past.

Table A1-1
Date of Receipt of Status Reports from Manufacturers
(Requested Date December 1, 1976)

Date	Report Received from	Comment
Nov. 21, 1975	Jensen	Early
Dec. 1, 1975	Chrysler	Only major one received on time
Dec. 2, 1975	Dresser	1 day late
Dec. 4, 1975	Questor	3 days late
Dec. 8, 1975	Toyo Kogyo	7 days late
	Honda	
	Fiat	
	Yamaha	
Dec. 10, 1975	Volvo	9 days late
	VW	
Dec. 11, 1975	Renault	10 days late
Dec. 11, 1975	Ford	11 days late
	Gould	
	Mitsubishi	
Dec. 15, 1975	GM	14 days late
	Toyota	
	Nissan	
Dec. 17, 1975	Ethyl	16 days late
Dec. 18, 1976	Peugeot	17 days late Pt. I only submitted
	Citroen	
Dec. 23, 1975	Saab	22 days late
Jan. 7, 1976	Daimler-Benz	37 days late
Jan. 13, 1976	BMW	43 days late Part I submitted Status Report not submitted - delayed
Jan. 16, 1976	Rolls-Royce	46 days late
Jan 23, 1976	American Motors	53 days late
Jan. 29, 1976	British Leyland	59 days late
Feb. 18, 1976	Porsche	78 days late
Feb. 24, 1976	Peugeot Diesel SR	84 days late
April 1, 1976	Fuji Heavy Industries	123 days late

APPENDIX 2

AN ESTIMATE OF THE POTENTIAL BENEFITS OF IMPROVING COLD-START EMISSION PERFORMANCE

The use of oxidation catalysts in providing control of hydrocarbons (HC) and carbon monoxide (CO) has been effective. One limit on the usefulness of the catalyst is the time immediately after a cold start during which time the catalyst is below operating temperature. This problem is accentuated, on the emission test because at this point in the cycle, the engine-out HC and CO emissions are high, due to cold start enrichment. That point at which the catalyst reaches operating temperature is known as "light-off".* If the catalyst would, or could be made to, light-off sooner than current systems reductions could be made in HC and CO emissions. A way this could be demonstrated is by a series of experiments on a representative sampling of automobiles.

Such data are not available. However, an estimate of the reduction in emissions can and has been made using 1976 Certification results. What has been done is to investigate the Bag 1 and Bag 3 emissions, primarily. Various ratios of Bag 1 to Bag 3 and Bag 1 to total emissions have been studied to obtain an idea of the importance of quick light-off performance of the system. Additionally, studies of the DF's for Bag 1 and Bag 3 have been made. These DF studies indicate deterioration in light-off (Bag 1) and in warmed-up efficiency (Bag 3).

As a surrogate to improved cold-start emission performance, Bag 1 was replaced by Bag 3 in the calculation of the total test emissions. This was done to estimate the potential benefits due to improved cold-start emission control. Whether or not the absolute benefits can be achieved or exceeded is conjectural at this time, but the analysis can indicate about how much of an emission control benefit may be there.

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* Typically the temperature at which 50% conversion efficiency is reached for HC and CO at a given space velocity for oxidation catalysts.

In the interest of including the greatest number of vehicles possible vehicles meeting Federal and/or California standards are included. Because the results are considered on a percent improvement basis any effects of interaction due to difference in emission level tend to be minimized.

The Federal Emission Test consists of a series of vehicle operating modes encompassing those most generally experienced during a typical driving schedule. After suitable preparation, the vehicle is operated on a chassis dynamometer for 1372 seconds which is equivalent to 7.5 miles under the dynamometer operating conditions. The first 505 seconds of operation is termed the "cold transient" portion, the remaining 867 second portion is called the "hot stabilized" portion of the test. The vehicle is allowed to stand with engine off (soak) for ten minutes and the vehicle is again operated as in the first 505 seconds of the preceding test. This is termed the "hot transient" portion. Exhaust gas samples are taken during the "cold transient" (Bag 1), "cold stabilized" (Bag 2), and "hot transient" (Bag 3) portion of the test. These samples are indicative of the exhaust gas composition of a vehicle during warm-up after a cold start (cold transient), operation in a warmed-up condition (cold stabilized), and operation after a start-up in a warmed-up condition (hot transient).

The emission results are computed by an equation which is weighted to take account of proportion of each mode in the operation of typical vehicles.* The transient mode is representative of operation after a start-up, either cold or hot, for a distance of 3.59 miles in 505 seconds.

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* CFR 86.075-26.

The stabilized mode is representative of operation during 3.59 miles in 867 seconds after the transient (hot or cold) mode. Vehicles in representative consumer use are considered to be represented by weighting Bag 1 by 0.43 and Bag 3 by 0.57.

Comparison of cold transient bag analysis (Bag 1) to hot transient bag analysis (Bag 3) can be used to evaluate exhaust emissions when the catalyst is at operating temperature earlier in the transient portion of the test cycle. In all cases studied the Bag 3 values were considerably lower than the corresponding Bag 1 counterparts for HC and CO. There was little effect on NOx. However, all of the credit for the lower Bag 3 values cannot be attributed to the catalyst. This is due to a warm start-up and this effect must be taken account of in evaluating the possible benefits of earlier catalyst light-off based on these data.

The next step in the study was to calculate mass emissions as per the Federal Procedure but using the hot transient (Bag 3) values instead of using the cold transient (Bag 1) values. These were termed "old composite" (FTP) and "new composite" (using Bag 3). The changes in HC, CO, and NOx were then computed as "percent reduction" based on the "old composite". The percent reduction in emissions calculated from substituting Bag 3 for Bag 1 is shown in Table A2-1.

The results from the calculations are shown on the following tables. For the sake of brevity,the only specific manufacturers mentioned are GM, Ford and Chrysler. However the "all" category includes all manufacturers for which there were data available, with the exception of Daimler-Benz and Peugeot. Those results were deleted due to the presence of Diesel data. In passing, it should be noted that Diesels do not have much of a "cold start" problem.

Table A2-1

Percent Reduction in Emissions Calculated From Substituting Bag 3 for Bag 1 Emissions

		Percent Reduction Actual Composite - Fabricated Composite Actual Composite		
Manufacturer or System Type	Number of Vehicles	HC	CO	NOx
Chrysler				
Chrysler	22	31.4	59.4	-0.6
Dodge	37	26.1	43.9	0.7
Plymouth	24	27.4	45.9	3.6
Ford				
Ford	94	11.9	44.1	-0.6
Mercury	33	20.3	32.4	2.9
General Motors				
Buick	23	43.1	45.6	11.1
Cadillac	10	44.3	80.5	5.5
Chevrolet	82	37.7	51.1	3.7
Oldsmobile	44	49.2	60.7	3.4
Pontiac	18	49.2	70.1	-1.3
All non-catalyst	192	13.2	21.2	1.8
All catalyst-no AIR	174	42.0	49.9	3.7
All catalyst+AIR	265	28.4	54.7	1.4
All catalyst	439	33.8	52.8	2.3
All Vehicles	631	27.5	43.2	2.2

Bar charts of the individual manufacturer results are shown as Figure A2-1 at the end of this Appendix.

Table A2-2

Cold Start to Total Emissions Ratios

Manufacturer or System Type	Number of Vehicles	0.43 Bag 1 Emissions / Total Emissions HC	CO	NOx
Chrysler	109	0.49	0.64	0.26
Ford	330	0.39	0.61	0.23
General Motors	251	0.58	0.68	0.28
All non-catalyst	268	0.34	0.38	0.27
All catalyst-no AIR	244	0.59	0.65	0.28
All catalyst+AIR	551	0.46	0.67	0.25

Table A2-3

DF's for Bag 1 and Bag 3 Separately

Manufacturer	Number of	DF Bag 1			DF Bag 3		
or System Type	Vehicles	HC	CO	NOx	HC	CO	NOx
Chrysler	7	0.99	0.77	1.00	1.20	1.08	0.99
General Motors	3	1.06	0.83	1.01	2.22	1.59	0.93
All	10	1.01	0.79	1.00	1.51	1.23	0.97

Only a few data points per vehicle were available, since bag data from manufacturer tests of durability cars is not reported.

Summary

Table A2-1 clearly indicates that benefits are obtainable from better cold start emission performance. Table A2-2 indicates that for current systems Bag 1 accounts for about 50 percent of the HC and about 65 percent of the CO of the entire test, depending on the system.

Tables A2-1 and A2-2 can be interpreted to indicate that pelleted catalysts like GM's have poorer light-off characteristics than some monoliths, like Ford's. This may be why GM has considered using a start catalyst and Ford has resisted it.

Table A2-3 can be interpreted in this manner. The DF for Bag 1 can be thought of as deterioration primarily due to catalyst light-off temperature increase. The DF for Bag 3 can be thought of as the deterioration in warmed up catalyst efficiency.

Table A2-3 indicates that the deterioration in warmed-up catalyst efficiency is greater than the deterioration in light-off performance. This implies that gains in catalyst hot efficiency are to be desired. Even though the DF for Bag 1 emissions is low, this does not mean that improved light-off techniques, like heat conservation, will not help emissions. Getting the catalyst to warm up quicker has benefits as indicated in Table A2-1. More data is needed before hard conclusions can be made about Bag 1 and Bag 3 DF's. Having only a few vehicles and a limited number of data points as a function of mileage may have affected the results.

Figures A2-2 through A2-4 show that lighter weight vehicles have not used oxidation catalysts as much as have the heavier vehicles. This is interpreted this to mean that light weight vehicles have an easier time in controlling emissions.

Figure A2-1

```
                              MEAN PERCENT REDUCTIONS BY MANUFACTURER
 I
 I AMERICAN MOTORS
 I
 IXXXXXXXXXXXXXXXXXXXX HC   19.8
 I############################################ CO   44.1
 I NOX  -0.0
 I
 I (CHRYS) CHRYSLER
 I
 IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX HC   31.4
 I########################################################### CO   59.4
*I NOX  -0.6
 I
 I (CHRYS) DODGE
 I
 IXXXXXXXXXXXXXXXXXXXXXXXXXX HC   26.1
 I############################################ CO   43.9
 I* NOX   0.7
 I
 I (CHRYS) PLYMOUTH
 I
 IXXXXXXXXXXXXXXXXXXXXXXXXXXX HC   27.4
 I############################################## CO   45.9
 I**** NOX   3.6
 I
 I (FO MO CO) FORD
 I
 IXXXXXXXXXXXX HC   11.9
 I############################################ CO   44.1
*I NOX  -0.6
 I
 I (FO MO CO) MERCURY
 I
 IXXXXXXXXXXXXXXXXXXXX HC   20.3
 I################################ CO   32.4
 I*** NOX   2.9
 I
 I (GM) BUICK
 I
 IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX HC   43.1
 I############################################## CO   45.6
 I*********** NOX  11.1
 I
 I (GM) CADILLAC
 I
 IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX HC   44.3
 I################################################################################ CO   80.5
 I****** NOX   5.5
 I
 I (GM) CHEVROLET
 I
 IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX HC   37.7
 I################################################### CO   51.1
 I**** NOX   3.7
```

Figure A2-1 (con't)

```
                                  MEAN PERCENT REDUCTIONS BY MANUFACTURER
I
I (GM) OLDSMOBILE
I
IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX HC   49.2
I############################################################# CO   60.7
I*** NOX   3.4
I
I (GM) PONTIAC
I
IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX HC   49.2
I###################################################################### CO   70.1
*I NOX  -1.3
I
I ASTON MARTIN
I
IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX HC   47.1
I################################################################################## CO   82.3
I*** NOX   2.7
I
I ALFA ROMEO
I
IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX HC   39.7
I################################### CO   34.5
I** NOX   1.9
I
I AVANTI
I
IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX HC   30.8
I################################################ CO   48.1
I****** NOX   5.8
I
I AUSTIN MORRIS (BLMC)
I
IXXXX HC    4.0
I########### CO   10.5
I* NOX   1.2
I
I BMW
I
IXXXXXXXXXXXXXXXXXXXXXXXXXXXX HC   27.7
I###################### CO   22.3
I*** NOX   3.2
I
I BRICKLIN
I
IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX HC   39.8
I################################################################################## CO   82.4
I** NOX   2.1
I
I CHECKER
I
IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX HC   44.3
I################################################################ CO   64.3
I******* NOX   7.0
```

Figure A2-1 (con't)

```
                                   MEAN PERCENT REDUCTIONS BY MANUFACTURER
I
I MERCEDES BENZ
I
IXXXXXXXXXXXXXXXXXXXXXX HC   22.4
I############################################ CO   43.9
I*** NOX   3.3
I
I FIAT
I
IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX HC   32.6
I########################### CO   27.1
I** NOX   1.9
I
I HONDA
I
IXXXXXXXXXXXXXXXXX HC   16.9
I#################### CO   20.1
*I NOX  -1.2
I
I ISUZU
I
IXXXXXXXXXXXXXXXXXXXXXXXXX HC   25.4
I############################################### CO   46.8
I** NOX   2.4
I
I JAGUAR (BLMC)
I
IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX HC   51.2
I############################################################### CO   62.5
I** NOX   2.1
I
I LOTUS
I
IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX HC   56.7
I################################################################## CO   65.5
I***** NOX   5.2
I
I NISSAN
I
IXXXXXXXXXXXXXXXXXXX HC   19.4
I################################## CO   33.8
I* NOX   1.4
I
I PEUGEOT
I
IXX HC    2.0
I######### CO    9.2
I*** NOX   3.4
I
I PORSCHE
I
IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX HC   31.7
I###################### CO   22.1
I*** NOX   2.9
```

Figure A2-1 (con't)

```
                                                  MEAN PERCENT REDUCTIONS BY MANUFACTURER

             I
             I RENAULT
             I
             IXXXXX HC    4.8
             I#################### CO   19.7
             I NOX  -0.4
             I
             I ROLLS-ROYCE
             I
             IXXXXXXXXXXXXXXXXXXXXXXXXXXX HC   26.7
             I########################## CO   25.6
             I* NOX   1.4
             I
             I SAAB
             I
             IXXXXXXXXXXXXXXXXXXXX HC   20.3
             I########## CO    9.7
             I**** NOX   3.9
             I
             I MITSUBISHI
             I
             IXXXXXXXXXXXXXXXXXX HC   17.5
             I################# CO   16.6
             I**** NOX   4.4
             I
             I SS AUTOMOBILE
             I
             IXXXXXXXX HC    7.4
             I############################ CO   27.5
             I** NOX   1.6
             I
             I TRIUMPH (BLMC)
             I
             IXXXXXXXXXXXXXX HC   14.3
             I######################## CO   23.8
             I* NOX   0.7
             I
             I STUTZ
             I
XXXXXXXXXXXXXI HC  -12.6
             I################################################## CO   50.3
             I********* NOX   9.1
             I
             I TOYO KOGYO
             I
             IXXXXXXXXXXXXXXXXXXXXX HC   20.7
             I########################## CO   25.5
             I***** NOX   4.5
             I
             I TOYOTA
             I
             IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX HC   35.2
             I####################################### CO   38.9
             I*** NOX   3.4
```

Figure A2-1 (con't)

```
                              MEAN PERCENT REDUCTIONS BY MANUFACTURER

   I
   I VOLKSWAGEN
   I
   IXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX HC   31.8
   I######################################## CO   40.2
   I** NOX   2.2
   I
   I VOLVO
   I
   IXXXXXXXXXXXXXXXXXXXXXXXXXX HC   25.8
   I##################################################### CO   52.8
   I** NOX   2.4
   I
   I AUDI
   I
   IXXXXXXXXXXXXXXXXXXXXXXXXX HC   25.3
   I################################################ CO   48.4
   I*** NOX   2.8
   I
   I FUJI HEAVY IND
   I
   IXXXXXXXXXXXXXX HC   14.3
   I#################### CO   19.8
***I NOX  -2.5
```

Figure A2-2

SCATTER PLOT ****** % FAMILIES W/O CATALYST VS INERTIA WEIGHT --- ALL VEHICLES ******
N= 13 OUT OF 13 2.PCTFML VS. 1.INERWT

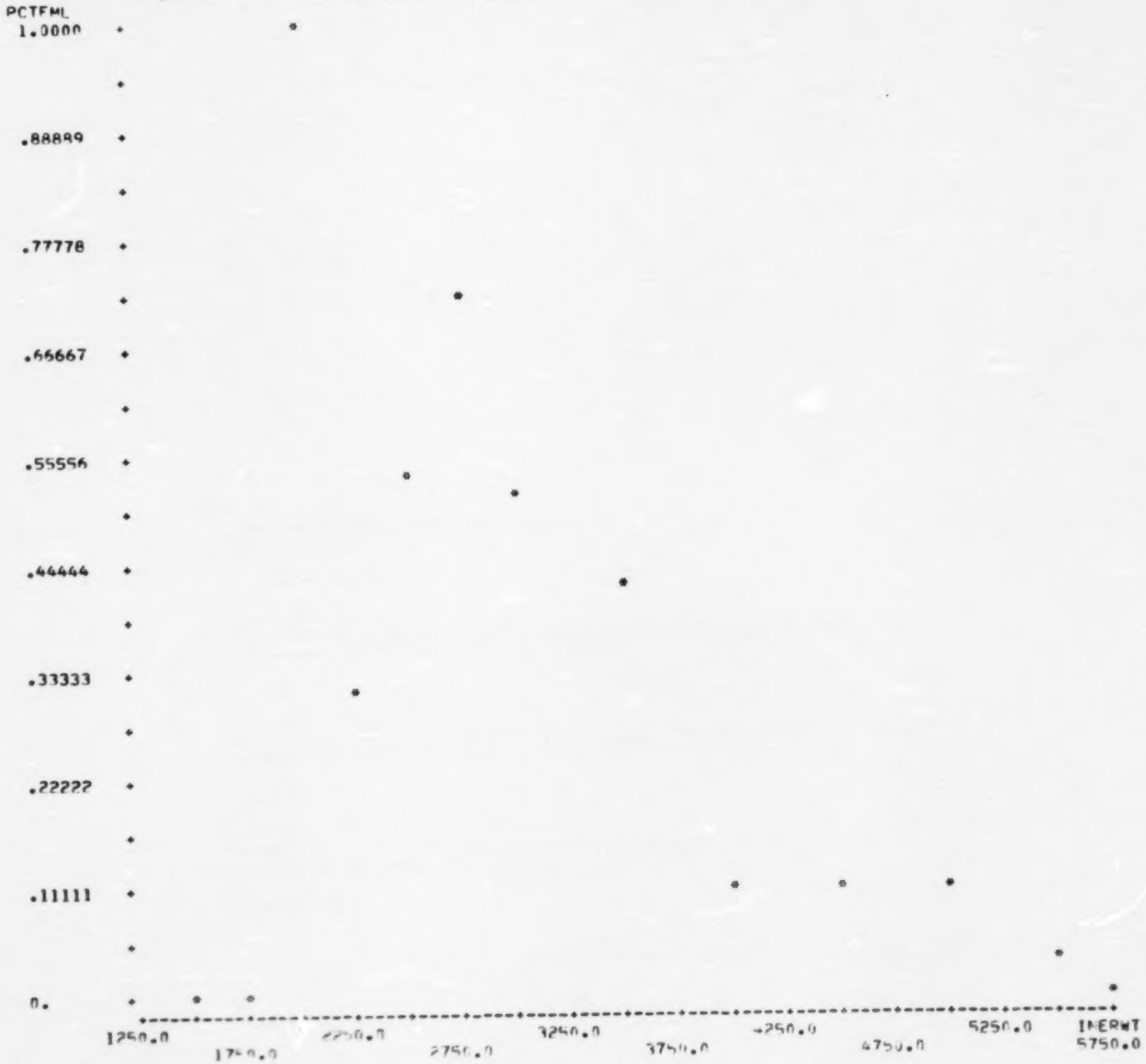

Figure A2-3

SCATTER PLOT ****** % FAMILIES W/O CATALYST VS INERTIA WEIGHT --- 49-STATE(FEDERAL) VEHICLES ******
N= 13 OUT OF 13 2.PCTFML VS. 1.INERWT

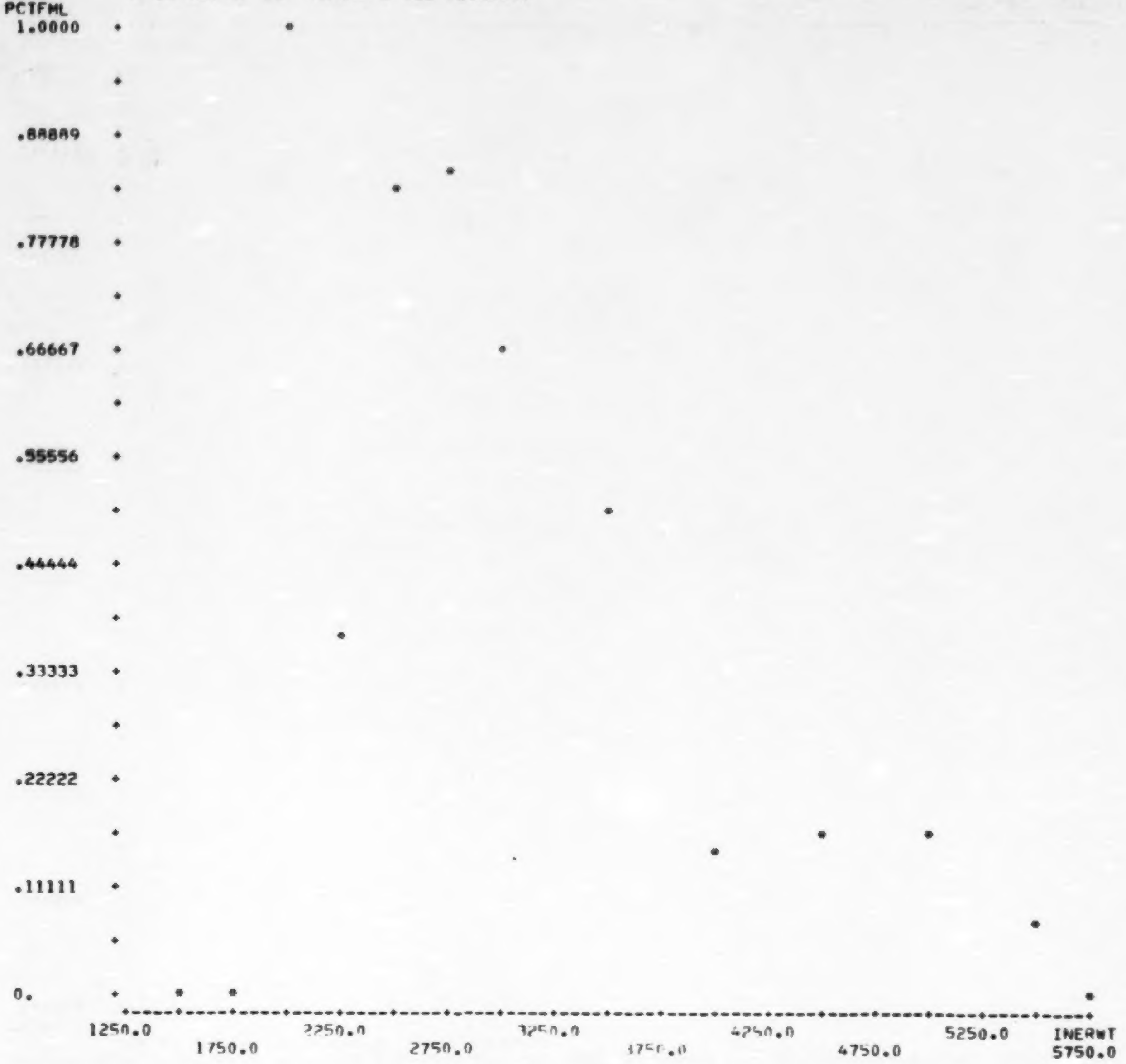

Figure A2-4

SCATTER PLOT ****** % FAMILIES W/O CATALYST VS INERTIA WEIGHT --- CALIFORNIA VEHICLES ******
N= 13 OUT OF 13 2.PCTFML VS. 1.INERWT